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SEWAGE TREATMENT FACILITIES FOR FEDERAL INSTALLATIONS

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SEWAGE TREATMENT FACILITIES FOR FEDERAL INSTALLATIONS

CLEAN WATER

TRAINING MANUAL

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FEDERAL WATER QUALITY ADMINISTRATION
U.S. DEPARTMENT OF THE INTERIOR

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SEWAGE TREATMENT FACILITIES FOR FEDERAL INSTALLATIONS

The training program

~~This course~~ is offered to supervisors, engineers, and other Federal personnel responsible for design, construction, or management of sewage disposal facilities at Federal installations. The course includes waste treatment methods which are applicable to Federal installations such as National Parks, Forest Service camps, small military installations, hospitals, schools and prisons.

Details of illustrations in
this document may be better
studied on microfiche.

U.S. DEPARTMENT OF THE INTERIOR
Federal Water Quality Administration
TRAINING PROGRAM

October 1970

I

FOREWORD

These manuals are prepared for reference use of students enrolled in scheduled training courses of the Federal Water Quality Administration.

Due to the limited production and availability of the manuals, it is not appropriate to cite them as technical references in bibliographies or other forms of publication.

References to products and manufacturers is for illustration only; such references do not imply product endorsement by the Federal Water Quality Administration or the U. S. Department of the Interior.

The reference outlines in this manual have been selected and developed with a goal of providing the student with a fund of the best available current information pertinent to the subject matter of the course. Individual instructors may provide additional material to cover special aspects of their own presentations.

This manual will be useful to anyone who has need for information on the subjects covered. However, it should be understood that the manual will have its greatest value as an adjunct to classroom presentations. The inherent advantages of classroom presentation is in the give-and-take discussions and exchange of information between and among students and the instructional staff.

Constructive suggestions for improvement in the coverage, content, and format of the manual are solicited and will be given full consideration.

H. M. Freeman
H. M. Freeman
Chief, Direct Training Branch
Division of Manpower and Training
Federal Water Quality Administration

TRAINING PROGRAM

The Federal Water Quality Administration of the U.S. Department of the Interior conducts programs of research, technical assistance, enforcement, and technical training for water pollution control.

Training is available at five installations of the Administration. These are: the National Training Center located at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio; the Robert S. Kerr Water Research Center, Ada, Oklahoma; the Southeast Water Laboratory, Athens, Georgia; the Pacific Northwest Water Laboratory, Corvallis, Oregon; and the Hudson-Delaware Basins Office, Edison, New Jersey.

The objectives of the Training Program are to provide specialized training in the field of water pollution control which will lead to rapid application of new research findings through updating of skills of technical and professional personnel, and to train new employees recruited from other professional or technical areas in the special skills required. Increasing attention is being given to development of special courses providing an overview of the nature, causes, prevention, and control of water pollution. These courses are being designed for nontechnical audiences, including administrators at the policy and decision-making levels, representatives of public action groups, and others not requiring the depth of detail of the more specialized courses.

Scientists, engineers, and recognized authorities from other FWQA programs, from other government agencies, universities, and industry supplement the training staff by serving as guest lecturers. Most training is conducted in the form of short-term courses of one or two weeks' duration. Subject matter includes selected practical features of plant operation and design, and water quality evaluation in field and laboratory. Specialized aspects and recent developments of sanitary engineering, chemistry, aquatic biology, microbiology, and field and laboratory techniques not generally available elsewhere, are included.

The primary role and responsibility of the States in the training of wastewater treatment plant operators are recognized. Technical support of operator-training programs of the States is available through technical consultations in the planning and development of operator-training courses. Guest appearances of instructors from the Federal Water Quality Administration, and the loan of instructional materials such as lesson plans and visual training aids, may be obtained through special arrangement. These training aids, including training manuals, may be reproduced freely by the states for their own training programs. Special categories of training for personnel engaged in treatment plant operations may be developed and made available to the States for their own further production and presentation.

An annual Bulletin of Courses is prepared and distributed by the Water Pollution Control Training Program. The Bulletin includes descriptions of courses, schedules, application blanks, and other appropriate information. Organizations and interested individuals not on the mailing list should request a copy from one of the training centers mentioned above.

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F. P. Nixon, Deputy Regional Training Officer

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THE FRESHWATER ENVIRONMENT

I INTRODUCTION

A We are interested in aquatic organisms because we are affected by them and we affect them in many ways.

B In this day of automation, they are nature's first continuously recording automatic pollution-meters.

C Our objective is to learn to read out or interpret the code.

D The first step is to understand the physical nature of the environment to which they are responding, and some of the interactions between this environment and the organisms which live in it.

II PHYSICAL FACTORS OF THE ENVIRONMENT

A Light is a fundamental source of energy for life and heat.

1 Insolation is affected by geographical location and meteorological factors.

2 Light penetration in water is affected by angle of incidence (geographical), turbidity, and color. The proportion of light reflected depends on the angle of incidence, the temperature, color and other qualities of the water. In general, as the depth increases arithmetically, the light tends to decrease geometrically. Blues, greens, and yellows tend to penetrate most deeply while ultra violet, violets, and orange-reds are most quickly absorbed. On the order of 90% of the total illumination which penetrates the surface film is absorbed in the first 10 meters of even the clearest water.

3 Turbidity may originate within or outside of a lake.

a That which comes in from outside (allochthonous) is predominantly inert solids (trypton).

b That of internal origin (autochthonous) tends to be biological in nature.

B Heat and temperature phenomena are important in aquatic ecology.

1 The total quantity of heat available to a body of water per year can be calculated and is known as the heat budget.

2 Heat is derived directly from insolation; also by transfer from air, internal friction, and other sources.

3 Heat not only affects the water physically, but also the rate at which biological processes take place.

C Density Phenomena (See Tables 1, 2, and 3)

1 Density and viscosity affect the flotation and locomotion of microorganisms.

a Pure fresh water achieves its maximum density at 4°C and its maximum viscosity at 0°C.

b Density is increased by dissolved solids.

2 Density stratification affects aquatic life and water uses, especially in lakes and reservoirs.

a In summer, a mass of warm surface water, the epilimnion, is usually present and separated from a cool deeper mass, the hypolimnion, by a relatively thin layer known as the thermocline.

b Ice cover and annual spring and fall overturns are due to successive seasonal changes in the relative densities of the epilimnion and the hypolimnion, profoundly influenced by prevailing meteorological conditions.

c The sudden exchange of water masses having different chemical characteristics may have catastrophic effects on certain biota.

d Silt laden waters may seek certain levels, depending on their own specific gravity in relation to existing layers already present.

e Saline waters will also stratify according to the relative densities of the various layers.

Table 1. EFFECTS OF TEMPERATURE ON DENSITY OF PURE WATER AND ICE*

Temperature (°C)	Density	
	Water	Ice**
-10	.99815	.9397
- 8	869	. 360
- 6	912	. 320
- 4	945	. 277
- 2	970	. 229
0	.99987 ----	.9168
2	997	
4	1.00000	
6	997	
8	988	
10	0.99973	

Table 2. EFFECTS OF DISSOLVED SOLIDS ON DENSITY

Dissolved Solids (Grams per liter)	Density (at 4°C)
0	1.00000
1	1.00085
2	1.00169
3	1.00251
10	1.00818
35 (mean for sea water)	1.02822

Table 3. VISCOSITY OF WATER

(In Millipoises at 1 Atm)

Temp. °C	Dissolved Solids in g/l			
	0	5	10	30
-10	26.0	---	---	---
- 5	21.4	---	---	---
0	17.94	18.1	18.24	18.7
5	15.19	15.3	15.5	16.0
10	13.10	13.2	13.4	13.8
30	8.00	8.1	8.2	8.6
100	2.84	---	---	---

3 The viscosity of water is greater at lower temperatures (see Table 3).

a This is important not only in situations involving the control of flowing water as in sand filter, but also since overcoming resistance to flow generates heat, it is significant in the heating of water by internal friction from wave and current action and may delay the establishment of anchor ice under critical conditions.

---

* Tabular values for density, etc., represent statistical estimates by various workers rather than absolute values, due to the variability of water. Water is not simply "H_2O" but in reality is a mixture of some 33 different substances involving three isotopes each of hydrogen and oxygen (ordinary hydrogen H^1, deuterium H^2, and tritium H^3; ordinary oxygen O^{16}, oxygen-17, and oxygen-18) plus 15 known types of ions. The molecules of a water mass tend to associate themselves as polymers rather than to remain as discrete units.

**Regular ice is known as "ice I." Four or more other "forms" of ice are known to exist (ice II, ice III, etc), having densities at 1 atm. pressure ranging from 1.1595 to 1.67. These are of extremely restricted occurrence and may be ignored in most routine operations.

b It is easier for plankton to remain suspended in cold viscous (and also dense) water than in less viscous warm water. This is reflected in differences in the appearance of winter vs. summer forms of life (also arctic vs. tropical).

D Shore development, depth, inflow-outflow pattern, and topographic features affect the behavior of the water.

E Water movements that may affect organisms include waves, currents, tides, seiches, and floods.

1 Waves or rhythmic movement

a The best known are traveling waves. These are effective only against objects near the surface. They have little effect on the movement of large masses of water.

b Standing waves or seiches occur in all lakes but are seldom large enough to be observed. An "internal seich" is an oscillation in a density mass within a lake with no surface manifestation may cause considerable water movement.

2 Currents

a Currents are arhythmic water movements which have major study only in oceanography. They primarily are concerned with the translocation of water masses. They may be generated internally by virtue of density changes, or externally by wind or runoff.

b Turbulence phenomena or eddy currents are largely responsible for lateral mixing in a current. These are of far more importance in the economy of a body of water than mere laminar flow.

F Surface Tension and the Surface Film

1 The surface film is the habitat of the "neuston," a group of particular importance in water supplies.

2 The biological effects of small amounts of detergents and similar agents are yet to be evaluated.

III DISSOLVED SUBSTANCES

A Carbon dioxide is released by plants and animals in respiration, but taken in by plants in photosynthesis.

B Oxygen is the biological complement of carbon dioxide, and necessary for all animal life.

C Nitrogen and phosphorus are fundamental nutrients for plant life.

1 Occur in great dilution, concentrated by plants.

2 The distribution of nitrogen compounds is generally correlated with the oxygen curve.

D Iron, manganese, sulphur, and silicon are other materials important to aquatic life which exhibit biological stratification.

E Many other minerals are present but their biological distribution in waters is less well known.

F Dissolved organic matter is present in even the purest of lakes.

IV BIOLOGICAL FACTORS

A Nutritional Classification of Organisms

1 Holophytic or independent organisms, like green plants, produce their own basic food elements from the physical environment.

2 Holozoic or dependent organisms, like animals, ingest and digest solid food particles of organic origin.

3 Saprophytic or carrion eating organisms, like many fungi and bacteria, digest and assimilate the dead bodies of other organisms or their products.

B The prey-predator relationship is simply one organism eating another.

C Toxic and Hormonic Relationships

1 Some organisms such as certain blue-green algae and some armored flagellates produce substances poisonous to others.

2 Antibiotic action in nature is not well understood but has been shown to play a very influential role in the economy of nature.

V BIOTIC COMMUNITIES

A Plankton are the macroscopic and microscopic animals, plants, bacteria, etc. floating free in the open water. Many clog filters, cause tastes, odors, and other troubles in water supplies.

1 Those that pass through a plankton net (No. 25 silk bolting cloth or equivalent) or sand filter are known as nannoplankton (which usually greatly exceed the net plankton in quantity).

2 Those less than four microns in length are sometimes called ultraplankton.

3 There are many ways in which plankton may be classified: taxonomic, ecological, industrial.

4 The concentration of plankton varies markedly in space and time.

a Depth, light currents, and water quality profoundly affect plankton distribution.

b The relative abundance of plankton in the various seasons is generally:

1 spring, 2 fall, 3 summer 4 winter.

B Benthic organisms (benthos) are those living on or near the bottom, frequently attached. Typically benthic organisms such as certain filamentous algae, may on occasion be broken or washed free, and mingled with the typical plankton.

C The emergent vascular shore plants are often a very influential community; on death and decay, they add nutrients to the water.

D The shallow water or littoral community of plants and animals is one of the most varied and productive areas - a fluctuating water level will discourage this community.

E The deep water bottom sludge or ooze communities may contribute tastes, odors, and undesirable chemical characteristics.

F The pelagic community is composed of those organisms that live naturally suspended or swimming in the open water, and includes most fishes.

VI THE EVOLUTION OF WATERS

A The history of a body of water determines its present condition. Natural waters have evolved in the course of geologic time to what we know today.

B In the course of their evolution, streams in general pass through four general stages of development which may be called: birth, youth, maturity, and old age.

1 Establishment or birth. In an extant stream, this might be a "dry run" or headwater stream-bed, before it had eroded down to the level of ground water.

2 Youthful streams; when the stream-bed is eroded below the ground water level, spring water enters and the stream becomes permanent.

3 Mature streams; have wide valleys, a developed flood plain, deeper, more turbid, and usually warmer water, sand, mud, silt, or clay bottom materials which shift with increase in flow.

4 In old age, streams have approached base level. During flood stage they scour their bed and deposit materials on the flood plain which may be very broad and flat. During normal flow the channel is refilled and many shifting bars are developed. (Under the influence of man this pattern may be broken up, or temporarily interrupted. Thus an essentially "youthful" stream might take on some of the characteristics of a "mature" stream following soil erosion, organic enrichment, and increased surface runoff. Correction of these conditions might likewise be followed by at least a partial reversion to the "original" condition).

C Geological factors which significantly affect the nature of a stream or lake include the following:

1 The geographical location of the drainage basin or watershed.

2 The size and shape of the drainage basin.

3 The general topography, i. e., mountainous or plains.

4 The character of the bedrocks and soils.

5 The character, amount, annual distribution, and rate of precipitation.

6 The natural vegetative cover of the land is of course responsible to many of the above factors and is also severely subject to the whims of civilization. This is one of the major factors determining runoff versus soil absorption, etc.

D Lakes have a developmental history which somewhat parallels that of streams.

1 The method of formation greatly influences the character and subsequent history of lakes.

2 Maturing of lakes

a If not already present shoal areas are developed through erosion of the shore by wave action and undertow.

b Currents produce bars across bays and thus cut off irregular areas.

c Silt brought in by tributary streams settles out in the quiet lake water.

d Rooted aquatics grow on shoals and bars, and in doing so cut off bays and contribute to the filling of the lake.

e Dissolved carbonates and other materials are precipitated in the deeper portions of the lake in part through the action of plants.

f When filling is well advanced sphagnum mats extend outward from the shore. These mats are followed by sedges and grasses which finally convert the lake into a marsh.

3 Extinction of lakes. After lakes reach maturity their progress toward filling up is accelerated. They become extinct through:

a The downcutting of the outlet.

b Filling with detritus eroded from the shores or brought in by tributary streams.

c Filling by the accumulation of the remains of vegetable materials growing in the lake itself.

(Often two or three processes may act concurrently)

VII PRODUCTIVITY

A The biological resultant of all physical and chemical factors is the quantity of life that may actually be present. The ability to produce this "biomass" is often referred to as the "productivity" of a body of water. This is neither good nor bad per se. A water of low productivity is a "poor" water biologically, and also a relatively "pure" or "clean" water; hence desirable as a water supply. A productive water on the other hand may be a nuisance to man or highly desirable. Some of the factors which influence the productivity of waters are as follows:

B Factors Affecting Stream Productivity (See Table 4)

To be productive of aquatic life, a stream must provide adequate nutrients, light, a suitable temperature, and time for growth to take place.

1 Youthful streams, especially on rock or sand substrates are low in essential nutrients. Temperatures in mountainous regions are usually low, and due to the steep gradient, time for growth is short. Although ample light is available, growth of true plankton is thus greatly limited.

2 As the stream flows toward a more "mature" condition nutrients tend to accumulate, and gradient diminishes and so time of flow increases, temperature tends to increase, and plankton flourish.

Should a heavy load of inert silt develop on the other hand, the turbidity would reduce the light penetration and consequently the general plankton production would diminish.

3 As the stream approaches base level (old age) and the time available for plankton growth increases, the balance between turbidity, nutrient levels, and temperature and other seasonal conditions, determines the overall productivity.

Table 4. EFFECT OF BOTTOM MATERIAL ON STREAM PRODUCTIVITY*

(The productivity of sand bottoms is taken as 1)

Bottom Material	Relative Productivity
Sand	1
Marl	6
Fine Gravel	9
Gravel and silt	14
Coarse gravel	32
Moss on fine gravel	89
Fissidens (moss) on coarse gravel	111
Ranunculus (water buttercup)	194
Watercress	301
Anacharis (waterweed)	452

*Selected from Tarzwell 1937

C Factors Affecting the Productivity of Lakes

1 The size, shape, and depth of the lake basin. Shallow water is more productive than deeper water since more light will reach the bottom to stimulate rooted plant growth. As a corollary, lakes with more shoreline, having more shallow water, are in general more productive. Broad shallow lakes and reservoirs have the greatest production potential (and hence should be avoided for water supplies).

Table 5. EFFECT OF BOTTOM MATERIAL ON LAKE PRODUCTIVITY*

(The productivity of sand bottoms is taken as 1)

Bottom Material	Relative Productivity
Sand	1
Pebbles	4
Clay	8
Flat rubble	9
Block rubble	11
Shelving rock	77

*Selected from Tarzwell 1937

2 Hard waters are generally more productive than soft waters as there are more plant nutrient minerals available. This is often greatly

influenced by the character of the soil and rocks in the watershed and the quality and quantity of ground water entering the lake. In general, pH ranges of 6.8 to 8.2 appear to be most productive.

3 Turbidity reduces productivity as light penetration is reduced.

4 The presence or absence of thermal stratification with its semi-annual turnovers affects productivity by distributing nutrients throughout the water mass.

5 Climate, temperature, prevalence of ice and snow, are also of course important.

D Factors Affecting the Productivity of Reservoirs

1 The productivity of reservoirs is governed by much the same principles as that of lakes, with the difference that the water level is much more under the control of man. Fluctuations in water level can be used to deliberately increase or decrease productivity. This can be demonstrated by a comparison of the TVA reservoirs which practice a summer drawdown with some of those in the west where a winter drawdown is the rule.

2 The level at which water is removed from a reservoir is also important. The hypolimnion may be anaerobic while the epilimnion is aerobic.

3 Reservoir discharges also profoundly affect the DO, temperature, and turbidity in the stream below a dam. Too much fluctuation in flow may permit sections of the stream to dry, or provide inadequate dilution for toxic waste.

VIII CLASSIFICATION OF LAKES AND RESERVOIRS

A The productivity of lakes and impoundments is such a conspicuous feature that it is often used as a convenient means of classification.

1 Oligotrophic lakes are the younger, less productive lakes, which are deep, have clear water, and usually support Salmonoid fishes in their deeper waters.

2 Eutrophic lakes are more mature, more turbid, and richer. They are usually shallower. They are richer in dissolved solids; N, P, and Ca are abundant. Plankton is abundant and there is often a rich bottom fauna.

3 Dystrophic lakes - bog lakes - low in pH, water yellow to brown, dissolved solids, N, P, and Ca scanty but humic materials abundant, bottom fauna and plankton poor, and fish species are limited.

B Reservoirs may be classified into two types, storage and run of the river.

1 Storage reservoirs have a large volume in relation to their inflow.

2 Run of the river reservoirs have a large flow through in relation to their storage value.

C According to location, lakes and reservoirs may be classified as polar, temperate, or tropical. Differences in climatic and geographic conditions result in differences in their biology.

IX THE MANAGEMENT OR CONTROL OF ENVIRONMENTAL FACTORS

A Liebig's Law of the Minimum states that productivity is limited by the nutrient present in the least amount at any given time relative to the assimilative capacity of the organism.

B Shelford's Law of Toleration:

Minimum Limit of Toleration		Range of Optimum of Factor	Maximum Limit of Toleration	
Absent	← Decreasing Abundance	Greatest Abundance	→ Decreasing Abundance	Absent

C The artificial introduction of nutrients (sewage pollution or fertilizer) thus tends to eliminate existing limiting minimums for some species and create intolerable maximums for other species.

1 Known limiting minimums may sometimes be deliberately maintained.

2 As the total available energy supply is increased, productivity tends to increase.

3 As productivity increases, the whole character of the water may be changed from a meagerly productive clear water lake (oligotrophic) to a highly productive and usually turbid lake (eutrophic).

4 Eutrophication leads to treatment troubles.

D Control of eutrophication may be accomplished by various means.

1 Watershed management, adequate preparation of reservoir sites, and pollution control tend to maintain minimum limiting nutritional factors.

2 Shading out the energy of insolation by roofing or inert turbidity; suppresses photosynthesis.

3 Introduction of substances toxic to some fundamental part of the food chain (such as copper sulphate) tends to temporarily inhibit productivity.

X POLLUTION

Pollution may be classified in many different ways. For example, the engineer might refer to sewage versus industrial wastes; or perhaps he might talk about organic, inorganic, and radioactive pollutants. From the environmental point of view, the following is suggested:

A Inert inorganic material which blankets and smothers bottom organisms, fills up their hiding places and drives them out into the open.

B Putrescible wastes which in high concentration may exhaust oxygen resources, or in low concentration may lead to intolerable eutrophication (or productivity).

C Toxic materials which may kill aquatic organisms.

D Wastes of significant heat content which may raise or lower the average annual temperature or "climate."

E Pollution which may affect man's use of aquatic products.

1 Radioactive wastes which render them dangerous to health.

2 Trace quantities of organic substances which may render the flavor unacceptable.

XI SUMMARY

A A body of water such as a lake represents an intricately balanced system in a state of dynamic equilibrium. Modification imposed at one point in the system automatically results in compensatory adjustments at associated points.

B The more thorough our knowledge of the entire system, the better we can judge where to impose control measures to achieve a desired result.

REFERENCES

1 Chamberlin, Thomas C. and Salisburg, Rollin P. Geology. 1: Geological Processes and Their Results. pp i-xix, and 1-654. Henry Holt and Company. New York, 1904.

2 Dorsey, N. Ernest. Properties of Ordinary Water - Substance. Reinhold Publ. Corp. New York. pp 1-673. 1940.

3 Hutcheson, George E. A Treatise on Limnology. John Wiley Company. 1957.

4 Ruttner, Franz. Fundamentals of Limnology. University of Toronto Press. pp 1-242. 1953.

5 Tarzwell, Clarence M. Experimental Evidence on the Value of Trout 1937 Stream Improvement in Michigan. American Fisheries Society Trans. 66:177-187. 1936.

6 U.S. Dept. of Health, Education, and Welfare. Public Health Service. Algae and Metropolitan Wastes. Transactions of a seminar held April 2.-29, 1960 at the Robert A. Taft Sanitary Engineering Center. Cincinnati, Ohio. No. SEC TR W61-3.

7 Ward and Whipple. Fresh Water Biology. (Introduction). John Wiley Company. 1918.

This outline was prepared by H. W. Jackson, Chief Biologist, National Training Center, FWQA, Cincinnati, OH 45226.

WATER RESOURCES AND NEEDS

I WATER RESOURCES

A The source of all freshwater is the hydrologic cycle, shown in Figure 1.

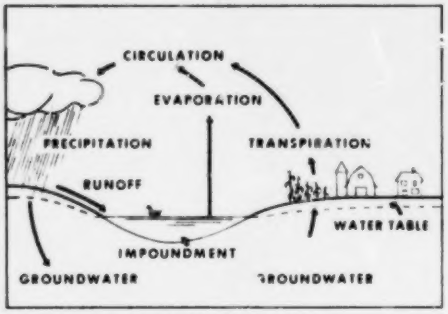


Figure 1

1 Precipitation of water as rain, snow, hail, sleet or dew.

2 Percolation of water through soil to an aquifer to form groundwater.

3 Runoff of water which forms lakes, streams and rivers.

4 Evaporation of surface water or transpiration of water from green plants to the atmosphere.

5 Atmospheric recirculation of the water vapor.

B The world's supply of water is contained within the hydrologic cycle as:

1 Oceanic water

2 Water vapor in the atmosphere

3 Ice and snow in glaciers and snowpack

4 Runoff water in lakes and streams

5 Groundwater

C Withdrawals for use are mostly from those waters in the runoff and groundwater phases, although some oceanic waters are being utilized.

D Precipitation--which serves to recharge groundwaters and surface supplies--is at a relatively fixed annual rate.

1 Average precipitation in the U.S. is 30 inches per year or 3,900 billion gallons per day.

2 Evapo-transpiration losses total approximately 21 inches per year or approximately 2,740 billion gallons per day.

3 The available water totals approximately 9 inches per year or 1,160 billion gallons per day.

II THE DISTRIBUTION OF U.S. WATER RESOURCES

Although the water supply in the hydrologic cycle is fixed in amount, it is not distributed evenly. A wide disparity of water distribution exists both in time and space. Distribution of the annual average precipitation is shown in Figure 2.

A Distribution of Precipitation

1 Dependent upon:

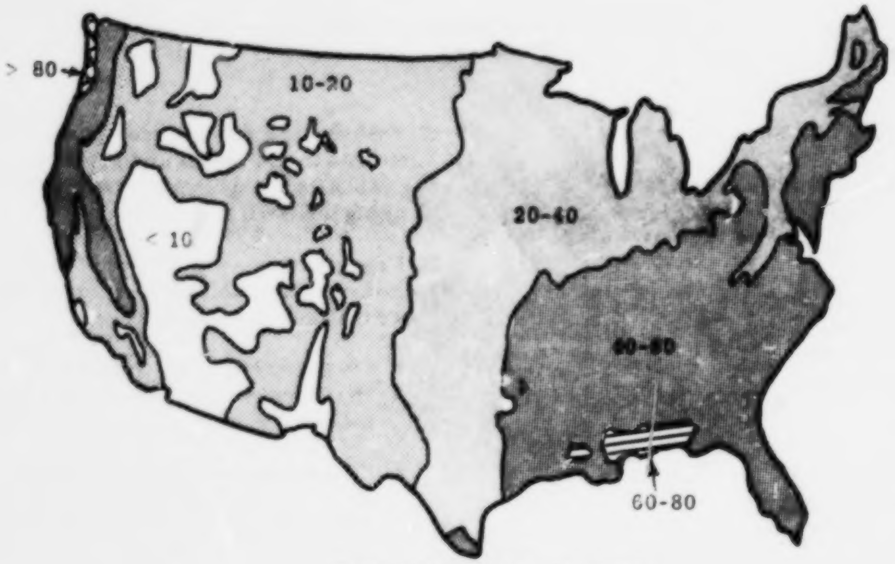
a Atmospheric conditions such as temperature and winds

b The geography of the region

c The general climate of the area

2 U.S. areas of high annual precipitation

a The Pacific slope varies from 10 inches to greater than 100 inches annually.



Distribution of Precipitation
(Average Annual)
Inches

Figure 2

b The gulf states precipitation varies from 20 to 60 inches annually.

c Precipitation in the midwest and Great Lakes area ranges from 25 to 50 inches per year.

d Precipitation along the Atlantic Coast averages between 35 to 50 inches per year.

3 Areas of low annual precipitation

a The Rocky Mountain area precipitation ranges between 10 and 20 inches per year.

b Much of the southwest has less than 10 inches of precipitation annually.

4 Distribution of precipitation with time

a The rainy or wet season varies from summer to winter, or in some areas there is relatively little change throughout the year.

b Local storms of high intensity may reach as much as 30 inches in 24 hours.

B Distribution of Runoff

1 Dependent upon:

a Precipitation in the region

b Infiltration - which is controlled by the geologic formations and the time lapse between rains.

c Season of the year controls evaporation, and snow melt.

d Topography controls the time available to percolate through the soil.

e Vegetation type and density affects interception and evapotranspiration.

2 Areas of high annual runoff

a Sections of the Pacific slope have greater than 80 inches annually.

b The eastern 1/3 of the U.S. averages greater than 20 inches of runoff annually.

3 Much of the western U.S. has less than 1 inch of runoff annually.

a Southwest

b Rocky Mountain states

c Rocky Mountain plateau

4 Time distribution of runoff

a Overflow--runoff during and immediately following precipitation.

b Base flow--sustained or fair weather runoff composed of delayed subsurface and groundwater runoff. See Figure 3 for runoff cycle.

C Distribution of Groundwater

1 Groundwater volume is affected by the same factors as runoff.

2 Geologic formations and soils control percolation and storage of groundwater.

3 Topography controls time available for percolation.

4 Evapo-transpiration varies with the season, as does precipitation and ground saturation.

III WATER USE

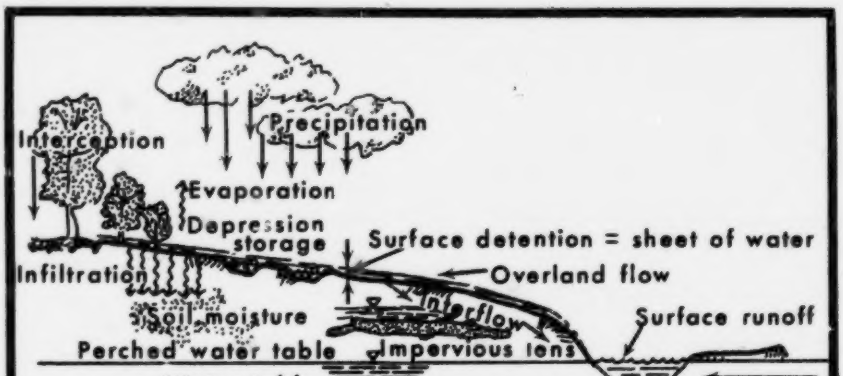
A Present Water Use in the U.S.

1 Water available for use

a Nine inches or 1,160 billion gallons per day are not lost through evapotranspiration, and is therefore theoretically available.

b Water use in the U.S. at the present time is approximately 350 billion gallons per day or 3 inches of our total supply.

c Twenty-one inches are lost through evapo-transpiration.


Interception
Precipitation
Evaporation
Depression storage
Surface detention = sheet of water
Infiltration
Overland flow
Interflow
Soil moisture
Surface runoff
Perched water table
Impervious lens
Water table
Ground-water flow
Stream channel

THE RUNOFF CYCLE
(Davis & DeWiest)
Figure 3

2 The way in which water is used

Water uses can be grouped into two classes. Those uses which are in situ such as recreation, fishing, and wildlife and those uses requiring withdrawal from the stream. These withdrawals are:

a Agricultural uses take 46% of our supply or 180 billion gallons/day; only 40% of this water is returned to the streams.

b Industrial uses take another 46% of our supply. 2% of the water used by industry is consumed.

c Municipal uses total approximately 25 billion gallons daily or 8% of the total.

3 Source of water used in U.S.

a National averages show 80% or 312 billion gallons per day to be from surface sources, while 20% is taken from the ground.

b The ratio of surface water to groundwater varies and is dependent on the quantity and quality available in each locality, as well as the cost.

4 Seasonal uses of water

a Irrigation waters are used during the growing season only.

b Some water using industries such as the canning industry are seasonal.

c The majority of industries needs water throughout the year.

d Municipal use is higher in the summer.

B Demand for water is increasing

1 The predicted demand of water in 1980 is approximately 600 billion gallons of water per day, or 220,000 billion per year.

2 This is mainly due to expansion of industry and irrigated agriculture.

3 Much of the demand for water will be in areas such as the southwest, that are already short on water.

C Methods for the Development of U.S. Water Resources for Future Needs

1 Utilization of our present sources of water, surface and groundwater, must be increased. This would mean increased storage, both on the surface and in underground reservoirs.

2 Desalinization of ocean waters and brackish waters holds some promise for regions where transportation will not be expensive.

3 Reduction of evapo-transpiration losses will greatly increase our total available supply.

4 Weather modification methods could possibly give us precipitation in the right place at the right time.

5 Greater reuse of our present supply is both through multiple use and better waste treatment methods.

IV SUMMARY

The total amount of water available appears to be fixed. In view of the increasing demands and the currently inefficient utilization of the supply, the demand may very shortly exceed the supply. Better management of the resource and more engineering research are urgently needed.

Table 1. AVAILABILITY OF GROUND WATER

Areas		Water Use (excluding water power) Use in mgd and Percent of total from Ground Water Sources	
		Total mgd	Ground water (%)
A	Atlantic and Gulf Coastal Plain area	32,000	25
B	Southern Great Plains area	21,000	45
C	Appalachian Mountain and Piedmont area	8,000	50
D	Rocky Mountains, northern Great Plains, and northern Pacific Coast area	28,000	12
E	Unglaciated central plateaus and lowlands	26,000	10
F-1	Basin and range	41,000	42
F-2	Columbia Plateau	24,000	7
G	Glaciated area of the East and Midwest	57,000	10
	U.S. Total (rounded)	240,000	20

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REFERENCES

1 Ackerman, Edward A., Lof, George O.G., Technology in American Water Development. The Johns Hopkins Press. Baltimore. 1959.

2 Senate Select Committee on National Water Resources: Water Resources Activities in the United States: Committee Print No. 3. U.S. Gov. Printing Office. January 1960.

3 Senate Select Committee on National Water Resources: Water Resources Activities in the United States: Committee Print No. 24. U.S. Gov. Printing Office. January 1960.

4 Linsley, Ray K., Kohler, Max A., Paulttus, Joseph H. Hydrology for Engineers. McGraw-Hill Book Co., Inc., New York. 1958.

5 Chow, Ven Te. Handbook of Applied Hydrology. McGraw-Hill Book Co., Inc., New York. 1964.

6 Davis, Stanley N. and DeWiest, Roger, J.M. Hydrogeology. John Wiley and Sons, Inc., New York. 1966.

7 American Chemical Society. Cleaning Our Environment the Chemical Basis for Action. ACS. Washington, DC 20036. 249 pp. (2.75) 1969.

This outline was prepared by Edward D. Schroeder, Engineer, formerly with FWPCA Training Activities, SEC and revised by L.J. Nielson, Chief Technical Training, Pacific Northwest Water Laboratory, Corvallis, Oregon.

EFFECTS OF POLLUTION ON AQUATIC LIFE

I INTRODUCTION

A The effluent from any given industrial plant may be combined with municipal sewage, and/or wastes from other industries. This may occur in the sewerage system or in a natural body of water.

1 Toxic wastes may inhibit biota of treatment plant as well as life in receiving stream.

2 Organic wastes may simply increase sewage-type load on plant and stream.

3 The above effects may be reinforced or neutralized by a complex of industrial wastes.

B The general overall character of a body of water may be subtly changed over a period of time.

II The principle of limiting factors (see Figure 1) deals with the response of organisms to various factors in the environment.

A Liebig's Law of the Minimum (Figure 1) states that the distribution of a species may be limited by one or more essential environmental factors which occur in minimal quantities.

B Shelford on the other hand pointed out in his Law of Tolerance (Figure 1) that there are also maximum values of most environmental factors which can be tolerated. In between these two extremes there are ranges which may be called "optimum" for factors useful to the organism. Purely deleterious factors on the other hand have a maximum tolerable value, but no optimum. The range between the maximum concentration (greater than zero) which kills no organism and the minimum concentration which kills all organisms is known as the "critical range."

C These principles apply to all aquatic life whether in a stream, lake, estuary, or treatment plant. They are the basis for the control or regulation of biological conditions.

III INDIRECT TOXICITY: MODIFICATIONS OF THE ENVIRONMENT WHICH AFFECT AQUATIC LIFE

A Deposition of inert precipitates and silt tends to smother bottom organisms. Contributing materials include silt or sand from erosion due to poor agricultural practices, rock flour or tailings from mining or quarry operations, mica, coal washings, sawdust and debris from lumbering, insoluble precipitates or complexes from chemical industries.

1 Vulnerable organisms include important fish foods such as insect larvae and snails; also fish eggs, bottom-living algae such as diatoms, and many others.

2 Physical injury to delicate membranes of eyes, and gills may also result.

3 Inert suspended materials and dyes reduce light penetration, suppress photosynthesis and hence biological productivity. They also prevent game fish and other predators from seeing their prey, thereby reducing the efficiency of food utilization.

The word "stream" should be interpreted in most cases to mean "river," "lake," "estuary," etc., as applicable.

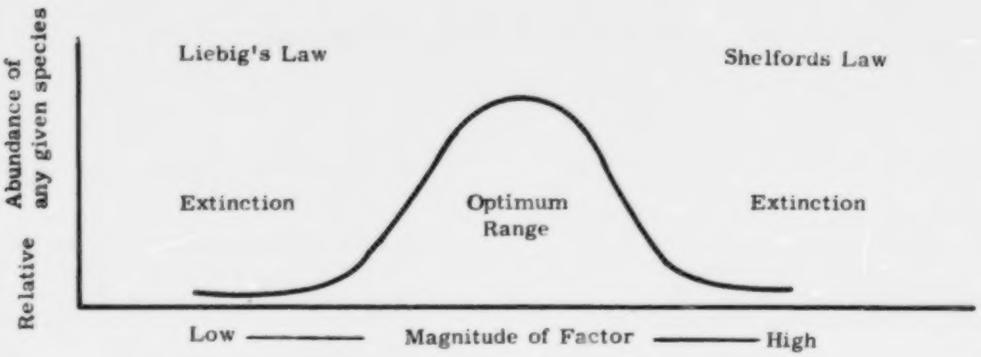

Figure 1. EFFECTS OF ENVIRONMENTAL FACTORS

B Wastes of significant heat content may change the "climate" of a body of water. Temperature may be higher or lower than normal.

1 Abnormally low summer temperatures may prevent the reproduction of some of the typical inhabitants, on the other hand colder water forms such as trout may be enabled to survive.

2 Abnormally high winter temperatures may encourage a rapid development of some species, thus for example, causing an early emergence of some insect followed by its death from normal winter temperatures. Southern forms may also invade more northerly waters, sometimes leading to a year-round nuisance from flying swarms of adults such as caddis flies.

3 Artificially produced high temperatures, often lack dependability. It is discouraging for organisms to spend six days in summer temperatures in January, only to freeze to death over the weekend because no one warned them that the plant would shut down!

4 Excessively high summer temperatures, even for a few hours once a year, probably represent the greatest temperature danger. Some species of fish can adjust to temperatures approaching 100° F, if the change takes place slowly. Each species however, has some maximum temperature above which it cannot survive (Figure 1).

a Quick temperature changes are fatal at much lower values.

b Lack of oxygen due to low solubility at high temperatures or from an increase in the rate of the BOD, also contributes greatly to high temperature mortalities.

C Oxygen-consuming wastes kill by depleting the free dissolved oxygen resources.

1 Amount present, rather than percentage of saturation, is usually more significant.

2 Minimum amounts rather than averages are most critical.

a Any species can survive something less than the optimum concentration of DO for a limited period of time. There is, however, some concentration for any given temperature, which will eventually result in the death of that species. Let us call this the "critical" DO.

b As the DO falls below the critical concentration, survival time eventually drops to zero.

c The absolute values of these thresholds vary with the species and other factors. Five mg O_2 per liter is often listed as a minimum permissible value to maintain a well-rounded healthy population of fishes on a year-round basis.

3 Low oxygen tensions may also increase the toxicity of certain chemicals.

D pH

1 "pH" is a logarithmic expression of the hydrogen ion concentration in a solution. Hydrogen ions (H+) in certain concentrations are toxic to aquatic life (as are also hydroxyl ions: OH^-). Aquatic life in relative abundance and variety can be found in waters ranging from approximately pH 5 to 9. Thriving communities including algae, insects, and fish have been studied in waters with a pH of at least 11.

2 Many species of aquatic organisms can adjust to pH values over a wide range. Sudden change of any kind however can be fatal.

3 Most metals and other toxic substances in dilute solution tend to become less toxic at high pH values. A notable exception is ammonia.

IV POLLUTION WHICH RENDERS FISH OR SHELLFISH UNUSABLE OR INTERFERES WITH THEIR CAPTURE

A Radioactivity at levels currently found in our waters has not been observed to adversely affect aquatic life itself. It may however, be taken up with food materials and render fish or fishery products unusable.

1 Radioactive nuclides (forms of chemicals) are taken up by the plants (predominantly algae) in the processes of photosynthesis and other types of protoplasmic synthesis. There is no selection between nuclides on the basis of radioactivity.

2 As the chemicals originally assimilated by the algae are "eaten up the food chain" (from algae to invertebrates to small fish to large fish to man and other predators) their radioactivity moves along with them.

3 Thus radioactivity is acquired by fishes essentially through food, and scarcely at all by direct assimilation or absorption.

4 Plankton-feeding organisms such as herrings, oysters, and clams acquire radioactivity directly from the algae on which they feed. Since they concentrate this food from large volumes of water, they may be much "hotter" than the surrounding water itself.

B Fish may be repelled or driven out of an area by obnoxious chemicals. This may simply result in their scarcity or absence from a given locale, or it may prevent their swimming up a river to spawn. In this case the species would soon disappear and be lost to the community.

C Color, odor, oil, floating scum, bacterial slimes, and other such materials tend to discourage sport fishing and interfere with gear used by commercial fisheries.

D Sublethal concentrations of chemicals such as phenol, benzene oil, 2-4-D, etc., may impart an unpleasant taste to fish flesh, even when present in very dilute concentrations. This is nearly as detrimental to the fisheries as a complete kill, and of course applies to shellfish as well as fin fish.

E Minamata disease was first described from Minamata, Japan, as a disorder resulting from eating various seafoods taken from Minamata Bay, Kyushu, Japan. The disease results from industrial toxicity, in this case an organic mercury compound, transmitted to a wide variety of local marine seafood species. These organisms are not known to be affected, but acting as "transvectors," pass the toxin along to predators or human consumers. Over 30% mortality occurred in Minamata among people eating local seafood.

1 It may be important to note that a fish kill was recently reported from a TVA lake in this country resulting from mercury leaching from corroded 50 gallon drums used as floats by a local marina.

2 Bird and fish kills have recently occurred in Swedish lakes resulting from mercury compounds from pulp mills. Levels in pike exceed the WHO standards for human consumption and the local population has been advised not to eat pike more than once a week! Cases of high mercury levels are increasing.

V DIRECT TOXICITY: AFFECTS THE ORGANISM ITSELF

Fish kills are often the result of direct toxicity. If this is sufficiently potent to kill at once, or within a few days, it is called acute, and is often observed as a "fish kill."

Action that may require weeks or months to be effective may be referred to as low-level, cumulative, or chronic toxicity, and is more often observed as simply a reduction of productivity: "Fishin' ain't what it used to be." Examples of chemicals often believed to be involved include: acids, alkalines, ammonia, chlorine, cyanides, metals, phenols, solvents, sulfides, synthetic organic chemicals, oil field brines, pesticides, herbicides, detergents and others.

A Acute toxicity may be so broadly effective that many forms of life are affected at one time, or it may be highly selective. It may result from a low concentration of a highly toxic material or a high concentration of a relatively less toxic material.

1 It is frequently encountered as a "slug" resulting from a dump or spill, followed by normal, relatively non-toxic conditions as the mass of water containing *the poison flows on downstream,* or is deflected by tidal movements.

2 Acute toxicity can be evaluated by means of the toxicity bioassay technique and various modifications (Figure 2).

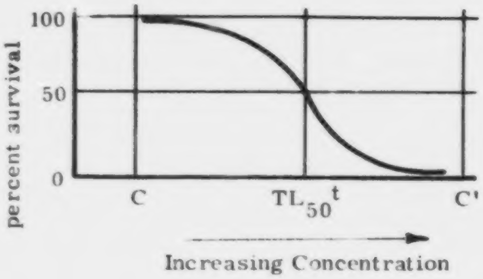

Figure 2 - Critical Range

C: maximum concentration at which no fish die, C': minimum concentration at which all die. TL_{50}^{t}, 50% tolerance limit (concentration tolerable to 50% of the population) for time t.

B Chronic or low-level toxicity may change the entire population balance.

1 Susceptible species of either fish or fish food organisms may die off, thereby permitting tolerant species to flourish for lack of competition.

2 If algae and/or invertebrate food organisms are killed off fish may die or move out of the area.

3 Weakened individuals are more susceptible to attack by parasites and disease, such as the aquatic fungus Saprolegnia.

4 Reproductive potential may be altered. Eggs or fry may or may not be more susceptible to toxic substances than adults.

5 Host fish for mussel (unionidae) life cycle may not survive.

6 The result may be a slow and subtle alteration of the characteristics of a stream over an extended period of time.

C The specific physiological mechanisms involved are infinite in variety and but little known. Included are such processes as enzyme inhibition as in the case with some of the pesticides, and over stimulation of mucous membranes of the gills, leading to death by suffocation.

D There are a number of excellent diagnostic techniques for the examination of dying fish, these include pathogenic bacteria, parasites, some metals, and certain pesticides. None are routine but require specific handling and preservation techniques.

E A recently developed procedure for protecting aquatic life from deleterious substances is biomonitoring. This is the continuous monitoring or surveillance of an effluent for toxicity by means of a system for exposing living organisms (such as fish or invertebrates) to a continuously flowing stream in a dilution just below the known danger point. Should the toxicity of the substance increase the test organisms respond in some recognizable manner, thus giving warning that corrective measures need to be initiated.

VI MECHANISMS OF POLLUTION TOLERANCE AND SENSITIVITY

The fact that some organisms are more resistant to pollution than others needs no emphasis. The matter of "why?" and "how?" on the other hand, is quite another question. In some cases the answer is obvious, in others not. In general we can say that the adaptations of certain species enable them to resist certain types of natural conditions such as organic deposits or sand bars. When man artificially creates conditions such as sludge banks, or sand bars, organisms which can tolerate such conditions move in, survive, and often thrive. Other forms are eliminated.

A Organic pollution is essentially non-toxic. Its typical result as noted above is oxygen depletion, physical turbidity, and smothering blankets of sediment or sludge.

B Devices and mechanisms for living in oxygen-poor or oxygen-free water include the following:

1 Obtaining oxygen from the air by means of periodic trips or access to the surface.

a The snorkel tube of the rat-tailed maggot.

b Periodic trips of the mosquito larvae and Corixidae or water boatmen. The mosquito takes air directly into its respiratory system, the water boatman into a trap or space beneath the wing covers, as well as into a layer of air held by fine hairs or "pile" all over its body.

c Behavior of the air breathing snails such as Physa which have an internal lung cavity.

d Insects which tap into air tubes in aquatic plants.

e Fishes which gulp air at surface or breathe surface water.

2 Special devices and behavior for respiration of water

a Hind intestine respiratory structures of dragonfly larvae permits respiration in silt-laden water.

b Movement of gill covers and similar structures in isopods and certain insect groups maintains a current of water over respiratory organs.

c Body movements of Tendipedid (chironomid) larvae create water current in tube. Sludge worms and other annelids also create water movement by means of sinuous body movements.

3 Physiological and behavioral adaptations to endure low oxygen tensions.

a Forms possessing accessory respiratory pigments such as hemoglobin might be expected to be able to be able to extract the last vestige of dissolved oxygen from the water. Two groups famous for resisting low DO do have hemoglobin: the larvae of certain Chironomid midge flies, and small annelid worms such as sludge worms. (it should be noted however, that the hemoglobin in each case is simply dissolved in the blood plasma, rather than being concentrated in special corpuscles as is the case in the more efficient vertebrate system.)

b The mere possession of hemoglobin however, does not seem to assure tolerance of low DO (Walshe '47). Larvae of the midge Tanytarsus spp. have hemoglobin, but will not tolerate oxygen-poor waters. Hemoglobin-bearing Chironomus bathopilus is moderately tolerant, and Chironomus plumosus is highly tolerant, however.

c During periods of low DO, Chironomus plumosus apparently respires carbohydrates as usual, but excretes excess lactic acid instead of accumulating it.

d Various species of Daphnia (microcrustacea) have been shown to accumulate hemoglobin in oxygen-poor waters but not in oxygen-rich waters (Fox '47). No clear adaptive significance has yet been proven however.

C Advantageous Feeding Habits

All highly organic pollution tolerant organisms are scavengers, and hence find an abundance of food. Most are relatively defenseless and hence have normally high reproductive rate. The result in a polluted situation is thus usually an extreme abundance.

D The reverse problem is why are intolerant species intolerant?

1 A physiological requirement for higher oxygen levels is probably most basic.

2 Turbidity would hamper any organisms employing sight in any way.

3 Absence of light would suppress the growth of green algae, and hence also restrict the growth of algae feeders.

E Inert silts by themselves have many damaging effects such as abrasive or smothering action.

Biological mechanisms for enduring inert silt or sand pollution are not numerous, and consequently such locations are usually known as biological deserts. Since some life exists even in deserts however, a few forms may occasionally be found. In general they are typical sand or mud dwellers. Since the available food in such a substrate is at best of a very low order, inhabitants of these situations must either seek buried or trapped food particles or capture food from the passing waters.

1 If there is no BOD involved, and water and oxygen circulate down into the deposit, burrowing forms such as certain mayflies, annelid worms, ammocetes lamprey larvae, microcrustaceans, and others may burrow down to depths of two feet or more. Fish eggs normally deposited in gravel and newly hatched larvae are also dependent on circulating water. Such a population can be killed overnight by a layer of fine sediment or sludge which seals the surface to water circulation.

2 Water or plankton feeders include clams and mussels which can move about freely in a soft, shifting bottom, thus keeping on top of silt or sand as

it accumulates. If deposition is actively taking place, however, there will probably be so much turbidity in the water that plankton (food) organisms are unable to live. Under such circumstances certain clams and snails have the ability to close the shell so tightly by means of valves or an operculum that all contact is lost with the environment for extended periods, during which CO_2 tends to lower the rate of body metabolism. Organisms of this type have been reported to be dug up with sand and gravel and incorporated into concrete products while still alive. Emergence of a population of asiatic clams (Corbicula) for example, just as a big block of concrete is setting is said to be rough on contractors!

3 An interesting situation occasionally develops in estuaries where mud of moderate organic content is slowly deposited over oyster beds. The oysters are unable to move, but as they grow, their shells tend to bend upward above the accumulating silt, and may grow to several inches in length while growing very little in width. Crowding brings about a similar reaction in the effort to avoid being buried.

F Few generalizations can be offered relative to toxic pollution except that toxicity is relative, and all forms do not respond equally to a given toxicant.

1 Few mechanisms of toleration can be listed, beyond the natural resistance that certain forms may have for a given condition. For example, some marine species may survive a salt concentration that is toxic to freshwater species. Over a period of several generations, some species may develop a genetic resistance to some toxicant such as insecticides in the same way that DDT-resistant strains of houseflies have developed. Copper sulfate, and chlorine-resistant strains of algae such as Cosmarium for example, may develop in treated water supply reservoirs.

2 Some bottom in-fauna organisms such as annelid worms may retreat down into burrows until a slug of undesirable water passes.

3 Molluscs may close shells tightly for the same purpose. The metabolic rate is known to diminish with the increase of CO_2 inside the closed shell, thereby enabling them to remain tightly sealed for extended periods of time.

VII EFFECTS OF LIFE HISTORY STAGES

A In order to survive in a polluted area, each life history stage of an indigenous organism must be able to survive in turn.

B If some given life history stage cannot tolerate conditions, and the species is present:

1 Fortuitous changes may occur at the proper time(s) to permit survival of the more susceptible stages(s) or:

2 Recruitment from less polluted areas may occur.

C Some examples of reproductive stages or procedures which might affect pollution sensitivity:

1 Egg or egg-like stages are often enclosed in protective membranes, jelly masses, or cases. May remain dormant until favorable conditions develop.

2 Eggs may be deposited in locations where they are less exposed to polluted water as:

buried in the gravel,
on the surface film,
on rocks over the water moistened by spray,
on mud surface near water,
or in locations where maximum water circulation is encountered as at lip of waterfall.

3 Eggs may require minimal DO due to low metabolic rate.

4 Eggs deposited on or in bottom may be susceptible to smothering.

5 Newly hatched larvae often continue to live on stored yolk material for a time. On beginning to take natural food, they may be killed by toxic content thereof, such as insecticide.

6 Some forms such as certain sludge worms commonly reproduce by (vegetative) fragmentation, hence avoiding egg and larva stages.

VIII NATURAL SELECTION AND ACCLIMATIZATION TO POLLUTION

A Known biological mechanisms for selective breeding of pollution resistant strains operate in nature among fishes as among other organisms.

1 Studies of population genetics indicate that after some finite number of generations of population stress (e.g., exposure to a given pollutant), permanent heritable resistance may be expected to develop.

2 If the environmental stress (or pollutant) is removed prior to the time that permanent resistance is developed in the population, reversion to the non-resistant condition may occur within a relatively few generations.

3 Habitats harboring populations under stress in this manner are often marked with the dead bodies of the unsuccessful individuals.

B Individual organisms on the other hand can over a period of time (less than one life cycle) develop a limited ability to tolerate different conditions, e.g., pollutants:

1 With reference to all categories of pollutants both relatively facultative and obligate species are encountered (e.g., euryhaline vs stenohaline, eurythermal vs stenothermal).

2 This temporary somatic acclimatization is not heritable.

C A given single-species collection or sample of living fishes may therefore represent one or more types of pollution resistance:

1 A sample of an original population which has been acclimated to a given stress in toto.

2 A sample of the surviving portion of an originalpopulation, which has been "selected" by the ability to endure the stress. The dead fish in a partial fish kill are that portion of the original population unable to endure the stress.

3 A sample of a sub-population of the original species in question which has in toto over a period of several generations developed a heritable stress resistance.

D Any given multi-species field collection will normally contain species illustrative of one or more of the conditions outlined above.

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REFERENCES

1 Cordone, A.J. and Kelley, D.W. The Influence of Inorganic Sediment on the Aquatic Life in Streams. Calif. Fish and Game. 47:189-228. No.2. 1961.

2 Ellis, M.M. Detection and Measurement of Stream Pollution. Bull. 22, U.S. Bur. Fish: also, Bull. Burg. Fish 48: 356-437. 1937.

3 Foster, R.F. and Davis, J.J. The Accumulation of Radioactive Substances in Aquatic Forms, No. A/Conf. 8/P/280. U.S.A. International Conf. on Peaceful Uses of Atomic Energy. pp. 1-7. 1955.

4 Ingram, W.M. and Towne, W.W. Stream Life Below Industrial Outfalls. Public Health Reports. 74:1059-1070. 1959.

5 Kurland, Leonard. The Outbreak of a Neurologic Disorder in Minimata, Japan, and its Relationship to the Ingestion of Seafood Contaminated by Mercuric Compounds. Proc. Nat. Shell. Sanit. Workshop. pp. 226-228. 1961.

6 Mackenthun, K.M. and Keup, L.E. Assessing Temperature Effects with Biology. Proc. Am. Power Conf. Vol. 31. pp. 335-343. 1969.

7 Tarzwell, C.M. and Gaufin, R.R. Some Important Biological Effects of Pollution Often Disregarded in Stream Surveys. Purdue Univ. Engr. Bull. Proceedings 8th Ind. Waste Conf. May 4, 5, and 6, 1953.

8 Tarzwell, C.M. Hazards of Pesticides to Fishes and the Aquatic Environment. The Use and Effects of Pesticides. Proc. of Symposium, Albany, N.Y. Sept. 23, 1963. N.Y. State Joint Legis. Comm. on Nat. Resources, Albany, N.Y. pp. 30-40.

9 Vinson, S.B., Boyd, C.E. and Ferguson, D.E. Resistance to DDT in the Mosquito Fish Gambusia affinis Science. 139:217-218. January 18, 1963.

10 Walshe, Barbara M. On the Function of Hemoglobin in Chironomus after Oxygen Lack. Jour. Exp. Biol. Cambridge. 124:329-342. 1947.

SUPPLEMENTARY READING

1 Bullock, Glen L. A Schematic Outline for the Presumptive Identification of Bacterial Diseases of Fish. Prog. Fish Cult. 23(4):147-151. 1961.

2 Foster, R.F. and Davis, J.J. Aquatic Life Water Quality Criteria. Second Progress Report, Aquatic Life Advisory Committee, Sewage and Ind. Wastes, 28:678-690. 1956.

3 Fox, H. Munro. Daphnia Hemoglobin. Nature. London. p. 431. September 27, 1947.

4 Ingram, W.M. and Wastler, III, T.A. Estuarine and Marine Pollution. Selected Studies, U.S. DHEW, PHS, Robt. A. Taft Sanitary Engineering Center, Cincinnati, Ohio. Technical Publication No. W6 1-04.

5 Jackson, H.W. and Brungs, Wm. A. Biomonitoring of Industrial Effluents. Purdue Industrial Waste Conference, Layfayette, Indiana. May 3-5, 1966.

6 Rodhe, W. Limnology, Social Welfare, and Lake Kinneret. Int. Jour. Limnology, Vol. 17. November 1969.

7 Tennessee Valley Authority, Fish Kill in Boone Reservoir. TVA Water Qual. Branch. Chattanooga, Tenn. 1968.

8 Robert A. Taft Sanitary Engineering Center. Pesticides in Soil and Water. An annotated Bibliography. PHS Publication No. 999-WP-17. September 1964.

9 Stewart, R. Keith, Ingram, William M. and Mackenthun, Kenneth. Selected Biological References on Fresh and Marine Waters. FWPCA Publication No. WP-23, pp. 126. 1966.

This outline was prepared by H.W. Jackson, Chief Biologist, National Training Center, FWQA, Cincinnati, OH 45226.

ORGANIC ENRICHMENT AND DISSOLVED OXYGEN RELATIONSHIPS IN WATER

I INTRODUCTION

A Oxygen normally composes approximately 20% of the atmosphere, but from only 0.5 to 1% of unpolluted water by volume (9 - 14 milligrams per liter, or parts per million).

B Physically, oxygen is a colorless gas, responsive to the laws of solubility, temperature, etc.

C The amount of oxygen present can be readily determined by various methods, both chemical and physical.

D Biologically, oxygen is one of the key elements to all life, all living organisms contain it along with hydrogen and carbon. It is the physiological "complement" of carbon dioxide.

E When properly interpreted, oxygen concentration can serve as an excellent index to water quality.

1 It is widely present.

2 It is intimately involved in many processes, chemical, physical, and biological.

II BIOLOGICAL OR PHYSIOLOGICAL RELATIONSHIPS (Figure 1)

A Photosynthesis is the biological starting point for synthesizing living substance out of non-living carbon dioxide, water, and other materials. In the process, radiant energy is adsorbed from the sun (hence it is an endothermic reaction) and free molecular oxygen is released to the environment as long as sufficient light is available, i.e., during daylight only.

1 The conventional empirical formula for photosynthesis is a very great simplification, as many as twenty steps may actually be involved (like respiration, controlled by systems of enzymes).

$$\begin{array}{l} 6\ CO_2 + 6\ H_2O + 673\ \text{Cal} \\ \quad\text{(Energy sunlight)} \\ \qquad\Bigg\downarrow \begin{array}{l}\text{chlorophyll} \\ \text{(enzyme system)}\end{array} \\ C_6H_{12}O_6 + 6\ O_2 \\ \text{(Simple sugar)} \end{array}$$

2 The end product is a basic organic material known as a simple sugar (carbohydrate, monosaccharide, of which "glucose" is an example, see Figures 1, A) which serves as a starting point for the elaboration of higher organic substances, and which may also be oxidized or "respired" by the cell to release the stored chemical energy.

3 Synthesis of organic materials (living protoplasm) from simple sugars and other substances in bacteria, algae, and man.

a Glucose and other simple sugar molecules can be combined by living organisms such as algae into other carbohydrates such as starch.

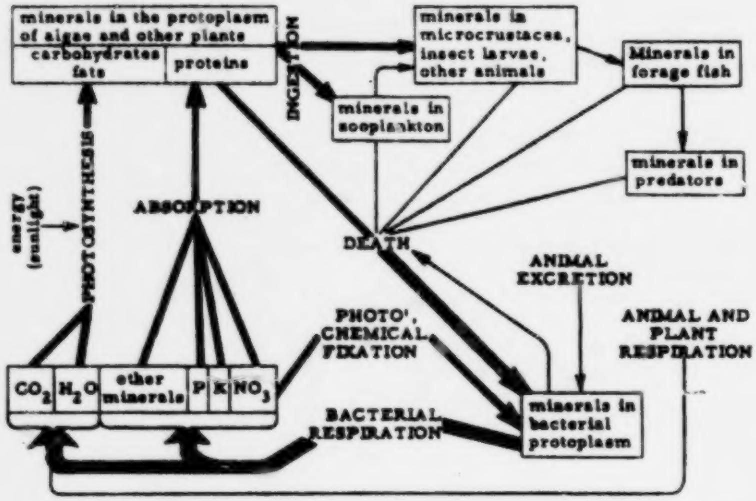
b After modification into fatty acids and glycerol, fats can be made.

c Combination with nitrogen and other minerals taken in from the surrounding water produces amino acids. These can then be combined into proteins, the most complicated of all life substances. Plants are the only organisms that can synthesize amino acids completely "from scratch."

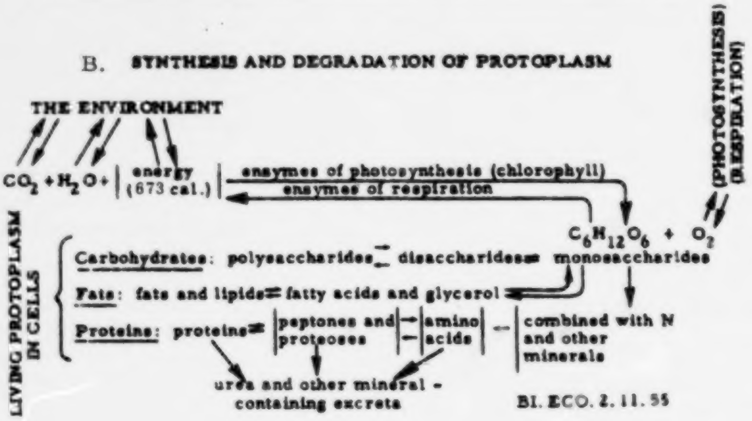
ENERGY CYCLES

H. W. Jackson

A. THE GENERAL FOOD CYCLE

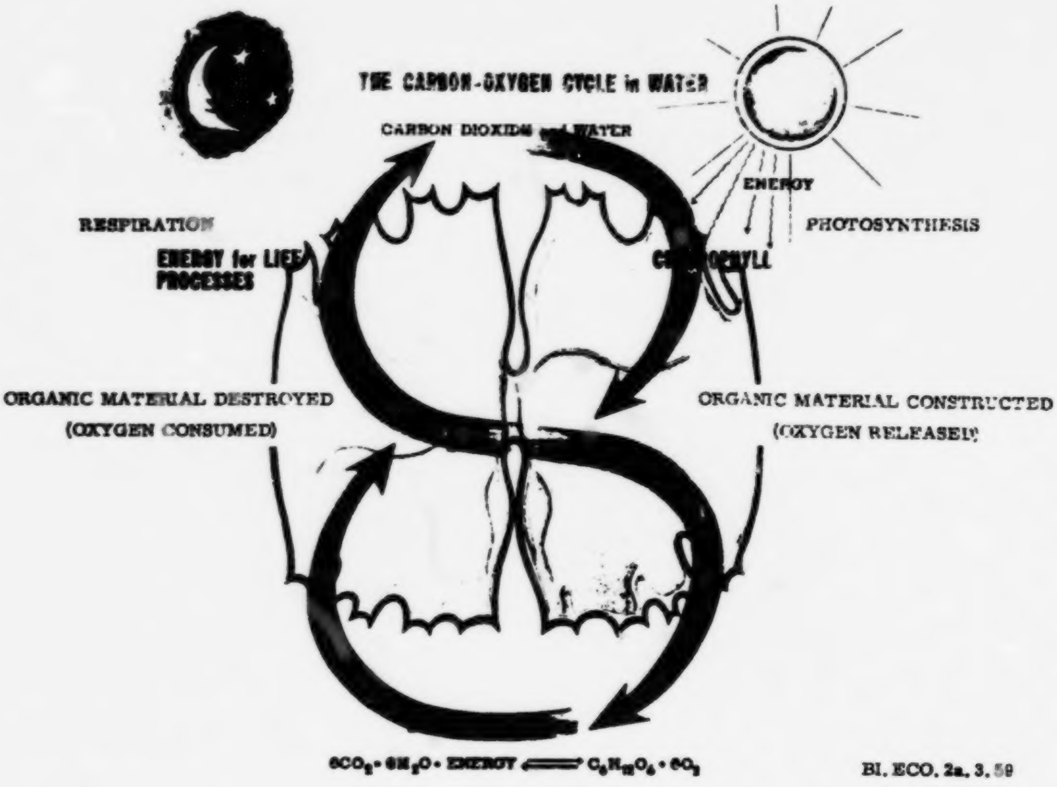

minerals in the protoplasm of algae and other plants
carbohydrates fats
proteins
INGESTION
minerals in microcrustaces, insect larvae, other animals
Minerals in forage fish
minerals in zooplankton
minerals in predators
energy (sunlight)
PHOTOSYNTHESIS
ABSORPTION
DEATH
ANIMAL EXCRETION
ANIMAL AND PLANT RESPIRATION
PHOTO', CHEMICAL FIXATION
CO_2
H_2O
other minerals
P
K
NO_3
BACTERIAL RESPIRATION
minerals in bacterial protoplasm

B. SYNTHESIS AND DEGRADATION OF PROTOPLASM


THE ENVIRONMENT
$CO_2 + H_2O +$
energy (673 cal.)
enzymes of photosynthesis (chlorophyll)
enzymes of respiration
$C_6H_{12}O_6 + O_2$
(PHOTOSYNTHESIS)
(RESPIRATION)
LIVING PROTOPLASM IN CELLS
Carbohydrates: polysaccharides ⇌ disaccharides ⇌ monosaccharides
Fats: fats and lipids ⇌ fatty acids and glycerol
Proteins: proteins ⇌ peptones and proteoses ⇌ amino acids ← combined with N and other minerals
urea and other mineral - containing excreta

BI. ECO. 2. 11. 55

Figure 1


THE CARBON-OXYGEN CYCLE in WATER
CARBON DIOXIDE and WATER
ENERGY
RESPIRATION
PHOTOSYNTHESIS
ENERGY for LIFE PROCESSES
CHLOROPHYLL
ORGANIC MATERIAL DESTROYED (OXYGEN CONSUMED)
ORGANIC MATERIAL CONSTRUCTED (OXYGEN RELEASED)
$6CO_2 + 6H_2O + ENERGY \rightleftharpoons C_6H_{12}O_6 + 6O_2$

BI. ECO. 2a. 3. 59

Figure 2

4 All of these synthetic or growth processes are endothermic and require energy to consummate. This energy is obtained by respiration.

B Respiration. Life processes such as those mentioned previously (II A 3, also physical movement) are energized by the controlled oxidation or "respiration" of single sugars. This is a cellular or physiological process and continues constantly in all living things, independently of light, as long as life persists.

1 Types of respiration. Respiration is an energy releasing or exothermic biochemical process and is to be distinguished from the external bodily act of "breathing", which is a process involving a lung, gill, or other organ, whereby molecular oxygen is brought inside the body of the organism and carbon dioxide is released. Breathing is transportation; respiration is burning or biochemical utilization.

a Aerobic respiration. The most common form of respiration is illustrated by the oxidation of glucose, using free dissolved oxygen from the environment. This is also the most efficient type since virtually all of the chemical energy contained in the glucose molecule is released (673 Cal.) and the residue is completely mineralized or stabilized to carbon dioxide and water.

Although actually taking place in more than twenty steps involving as many different enzymes, the overall process can be empirically represented by the following formula:

$C_6H_{12}O_6 + 6\,O_2$

(a simple sugar such as glucose)

$\downarrow$

$6\,CO_2 + 6\,H_2O + 673$ Cal

(enzymes) (energy)

b Anaerobic respiration. If free dissolved oxygen (DO) is not available from the environment, certain types of bacteria, fungi, and other organisms known as "facultative aerobes" can switch to another, less efficient type of respiration and still obtain energy by breaking down simple sugars. This is known as anaerobic respiration. Some types of microorganisms, the true anaerobes, can thrive only under anaerobic conditions.

The anaerobic respiration of glucose involves splitting the molecule without the use of outside oxygen so as to release some of the contained energy, but not all. The remainder is still available in the end products. A common empirical relationship is as follows:

$3\,C_3H_{12}O_6 \longrightarrow 2\,CH_3(COOH)_2$

(glucose) (enzymes) (lactic acid)

$+ 2\,CH_3CH_2OH + 2\,CH_3\,COOH$

(ethyl alcohol) (acetic acid)

$+ \dfrac{59\ 1/2 \text{ Cal}}{\text{(energy)}}$

c Anaerobic respiration of proteins and their derivations by microorganisms (known as putrefaction) often leads to the production of foul smelling end products. Aerobic respiration of proteins (known as decay) seldom produces offensive odors. In addition to carbohydrates, proteins, fats, and various other natural and unnatural hydrocarbons, and other substances can also be broken down or respired to relatively stable end products by microorganisms.

2 The adaptability of life is remarkable. By the same mechanisms of genetics and natural selection which have resulted in the evolution of present day life on earth, microorganisms have evolved which are capable of obtaining energy from, or in other words, "respiring" a great variety of new synthetic materials, the products of modern industry. This is the basis for the biological treatment of wastes.

a The types of biological mechanisms involved, in general, are known and to a degree, understood.

b Many species or kinds of organisms may be involved in the stabilization of a single type of waste.

3 Significance of respiration in sanitary engineering. The process of respiration uses or "demands" oxygen from the environment. Any material, such as sewage, an organic industrial waste, motor oil, etc., which will support life of any kind will thus exert (through the organisms living on it) a "BOD".

a Respiration has two end "products": energy, by which the organisms live, and degraded, mineralized, or stabilized material such as digested sewage sludge which retains little or no energy available to organisms. That is, they have no biochemical oxygen demand or BOD remaining.

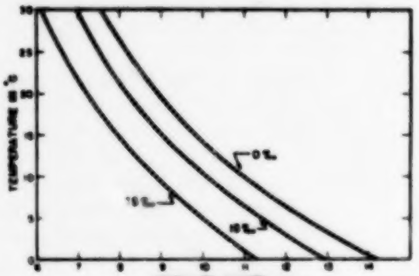
b Since it is independent of light, it goes on night and day.

III PHYSICAL PHENOMENA

A Solubility of oxygen in pure water varies with temperature and pressure according to well known laws and values.

1 We expect to find less oxygen in warmer waters and more in colder. This has both seasonal and geographical implications.

2 Dissolved substances such as salts tend to reduce the solubility of oxygen at a given temperature (See Figure 3 - Oxygen Solubility at Selected Salinities).



OXYGEN SOLUBILITY AT SELECTED SALINITIES

Figure 3

3 The concentration of oxygen often is expressed as percent of saturation.

a Organisms, however, are affected by the real quantities present, and actually demand the most oxygen at the highest temperature, when the solubility is lowest.

b It is therefore more significant, where organisms and stream conditions are concerned, to express concentration as milligrams per liter (or parts per million).

B The movement or distribution of oxygen throughout a water mass is not entirely dependent on molecular diffusion, but also involves various types of gross water movements. Reaeration (or aeration) is the transfer of oxygen from the air into the water mass.

IV CHEMICAL FACTORS

A Chemical toxicity may delay the exertion of biological oxygen demands, or the release of oxygen by biological mechanisms.

B Chemical substances may themselves demand oxygen from the water.

1 If oxygen is available, the chemical oxygen demands tend to be satisfied relatively quickly and hence are likely to be a more local problem.

2 They are independent of any biological effect.

3 They are in addition to biological action.

V OXYGEN AND EUTROPHICATION

A Diurnal interactions of photosynthesis and respiration. (Figure 6)

1 Life, growth, and hence the need for oxygen for respiration continue twenty-four hours a day, as long as life persists.

2 Since photosynthesis in nature is activated by radiant energy from the sun, it is operative only during the daytime. It releases approximately twenty times as much oxygen as is consumed in cellular respiration, however, so there is a great excess left over which diffuses out into the surrounding water. Here it is available to biochemical oxidative demands of other organisms with the result that the ecological system becomes "aerobic."

3 DO's affected by photosynthesis thus tend to be highest in the daytime (particularly mid-afternoon) and lowest at night (3 - 4 A.M.).

B Organic materials from domestic sewage or similar wastes are readily available to microorganisms. Assimilation of food, and growth and multiplication of the population can thus begin relatively quickly, thus establishing a demand for oxygen for respiration.

1 It takes a significant period of time for a population of bacteria, fungi, and other microorganisms such as protozoa to become established, after the initiation of growth of the few original organisms, even under the best of conditions.

2 Dissolved oxygen does not thus disappear instantly from the water upon the admixture of sewage, but rather begins to diminish slowly. As the population of oxygen consuming organisms builds up, the deficit in the water increases. As this occurs, any equilibrium which may have existed with the atmosphere is destroyed, and the rate of aeration through the surface film increases.

a As the population of microorganisms grows still larger, its rate of increase begins to increase (logarithmic growth). Very soon a size of population is achieved where the demand for oxygen exceeds the amount which can be supplied through the surface film. The concentration of free DO now begins to drop sharply and may go to zero.

b If sufficient food for the microorganisms remains, anaerobic conditions will now prevail. Oxygen, of course, continues to enter at a maximum rate through the surface film, but is immediately used up. The overall rate of oxidation of the waste or food material however, is now very low (although the total amount may be large), as surface aeration can supply but a small portion of the oxygen needed.

c If there is no replenishment of the food supply by repollution, the big population of fungi and bacteria eventually uses up most of the available substrate or food, and begins to starve. Growth now begins to slow down, and the population eventually drops back to its original low level.

d Meanwhile time has passed. An abundance of fundamental plant nutrients such as nitrate, phosphate, potash, etc., have been released to the water as a result of microbial respiration. Algae begin to grow on this substrate, and increase rapidly to tremendous numbers.

e Algal photosynthesis thus suddenly begins to release great quantities of oxygen in the daytime. At first this is exhausted each night by respiration of the algae and other microorganisms, but soon persists around the clock until the algae in turn have exhausted their food supply and return to numbers normal for an unpolluted stream.

f With the above mentioned advent of free DO from the algae, the more efficient aerobic type of respiration can again be employed by the microorganisms. This hastens the oxidation or stabilization process, and leaves behind but a minimum residue of well mineralized material to accumulate on the bottom.

g It should be mentioned that turbidity from suspended microorganisms and other organic solids frequently inhibit the establishment of an algal population until the biochemical oxidation or stabilization process has been well started. Turbidity inhibits algal growth primarily by shading and suppression of photosynthesis.

C When organic material is dumped into a body of water faster than it can be oxidized by the mechanism described above, it tends to accumulate on the bottom in a partially digested condition known as sludge.

1 Great quantities of nutrient energy are still present, as well as a huge population of microorganisms. There is a very great need for oxygen which, if available, is avidly taken up by the organisms in the surface layers.

a Aerobic conditions in the overlying waters thus tend to hasten the stabilization of sludge banks by providing oxygen for aerobic type respiration.

b Anaerobic waters, on the other hand, tend to preserve the sludge by restricting all organisms to anaerobic types of respiration. It has been reported that the speed of decomposition begins to be restricted at concentrations below 1 ppm.

2 Anaerobic conditions are present throughout the sludge mass below the surface. Stabilization is still proceeding, but at a much slower rate than if oxygen were present.

D In the deeper reservoirs, lakes, rivers, and estuaries thermal stratification may develop in the summer.

1 The epilimnion or upper layer, being in contact with the atmosphere, receives a continual replenishment of oxygen by aeration processes.

2 If turbidity is not excessive, photosynthesis by algae (Figure 5) will also provide oxygen.

3 The hypolimnion or lower layer, being separated from the atmosphere and frequently from the light, tends to acquire an excess of carbon dioxide and a deficiency of oxygen due to the respiratory activities of microorganisms (such as protozoa, fungi, and bacteria). (Figure 4)
This effect is heightened if the bottom material is high in organic content as has been shown below.

Figure 4
Non-Pigmented, Non-Oxygen-Producing, Protozoan Flagellates

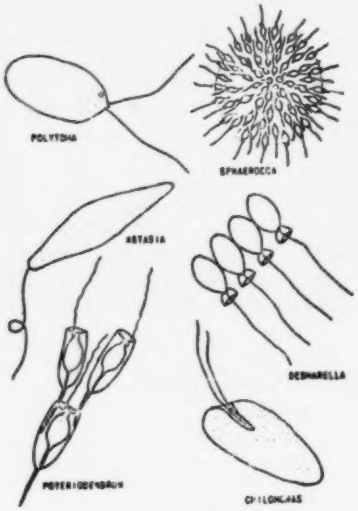
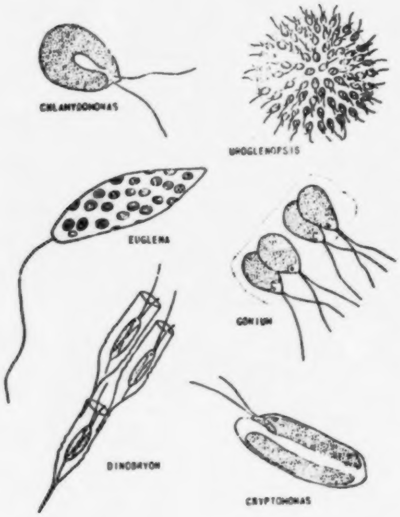


Figure 5
Pigmented, Oxygen-Producing, Algal Flagellates



VI PROBLEMS AND BENEFITS RESULTING FROM ALGAE PRODUCTION
(Figures 4, 5, 6)

A Problems to man may result when the total "primary production" by algae leads to an increase in the total organic content of the water that interferes with a desired use.

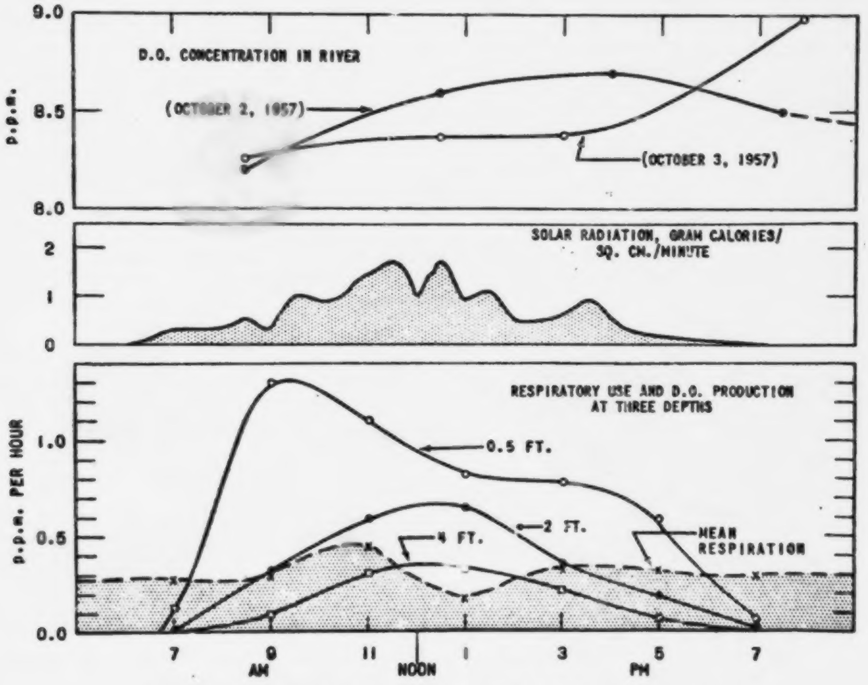
1 This may consist of a high algal population that produces a water with high turbidity, taste and odor, or other undesirable effect. High respiratory needs may lead to nocturnal oxygen deficit.

2 Certain algae may cause tastes and odors, clog filters; or otherwise interfere with potable water processing.

3 Death of large algal populations may lead to obnoxious odors through bacterial decomposition. Oxygen deficits may result at any time of day in this process. Deposition of masses of organic sediment or sludge in estuaries and back waters may be considerable.

B The primary production of algae can also serve as a supply of food to consumer organisms (animals), resulting in increased production at several (trophic) levels: (Figure 7)

zoömicrobes, microinvertebrates, macroinvertebrates, fishes.



DISSOLVED OXYGEN RELATIONS IN OHIO RIVER (REACH 11, BROMLEY)
OCT. 3, 1957

Figure 6

Mean Surface Water Productivity Rates of the Great Lakes and Other Freshwater Lakes and Ocean Areas.

Lake or Ocean and Location	Productivity Rate in mg.C/ m^3 /day	Investigator
Lake Superior	16.62	Parkos (1967-68)
Lake Huron	23.04	Parkos (1968)
Lake Michigan	37.62	Parkos (1967)
Lake Erie	175.20	Parkos (1968)
Grand Traverse Bay, N.E. Lake Michigan	0.34	Saunders et al. (1962)
Douglas Lake, Mich.	0.23	Saunders et al. (1962)
Bras d'Or Lake, Nova Scotia, Canada	23.5	Geen and Hargrave (1966)
Brooks Lake, Alaska	3.2	Goldman (1960)
Maknek Lake, Alaska	8.8	Goldman (1960)
Torne Träsk, Sweden	6.4	Rodhe (1958b)
Ransaren, Sweden	8.8	Rodhe (1958b)
Lake Erken, Sweden	221.0	Rodhe (1958b)
Lake Esrom, Denmark	1600	Jonasson and Mathiesen (1959)
Lake Furesø, Denmark	2100	Jonasson and Mathiesen (1959)
N.E. Atlantic - near Denmark	21	Steemann-Nielsen (1960)
North Atlantic, same lat. as Great Lakes	7.5	Steemann-Nielsen (1958b)
Southeast Pacific	3.3	Holmes (1961)
Southwest Pacific	7.2	Angot (1961)
North Pacific, Sub-Arctic Region	6.4	Koblentz-Mishke (1961)

Figure 7

1 Earlier notation cited the release of oxygen during utilization of CO_2 during algal photosynthesis. This encourages fungal or bacterial breakdown of pollutants.

2 Photosynthesis occurs in the presence of adequate light and favorable conditions. In darkness, the cells continue to respire and may consume more oxygen than they produced because photosynthesis increases the organic load.

3 Photosynthesis tends to occur at the surface where light intensity is greatest (Figure 6). Poor vertical mixing would result in stratification of water supersaturated with oxygen over oxygen deficient water. Depending upon conditions, a significant fraction of the oxygen could be lost to the atmosphere.

ACKNOWLEDGEMENTS:

This outline contains certain material submitted by F. J. Ludzack and M. E. Bender.

REFERENCES

1 Anonymous. Aquatic Life Water Quality Criteria. Aquatic Life Advisory Committee on the Ohio River Valley Water Sanitation Commission. Second Progress Report. Sewage and Ind. Wastes. 28(5):678-690. 1956.

2 Anonymous. Oxygen Relationships in Streams. Proc. of Sem. at R. A. Taft Sanitary Engineering Center. October 30 - November 1, 1957.

3 Bartsch, A.F. Algae in Relation to Oxidation Processes in Natural Waters. Special Publ. No. 2. Ecology of Algae. Pymatuning Lab. of Field Biology. U. of Pittsburgh. Pittsburgh, Pa. pp. 56-71.

4 Carpenter, J.H., Pritchard, D.W., and Whaley, R.C. Observations of Eutrophication and Nutrient Cycles in Some Coastal Plain Estuaries. in: Eutrophication: Causes, Consequences, Correctives; pp. 210-221. Proc. of Symposium. June 11-15, 1967. Publ. Nat. Acad. Sci. Washington, DC. 1969.

5 Custer, S.W. and Krutchkoff, R.G. Stochastic Model for BOD and DO in Estuaries. ASCE. Jour. San. Eng. Div. Vol. 95. pp. 865-886. 1969.

6 Ketchum, B.H. Eutrophication of Estuaries. in Eutrophication: Causes, Consequences, Correctives; pp. 197-209. Proc. of Symposium. June 11-15, 1967. Publ. Nat. Acad. Sci. Washington, DC. 1969.

7 Olsen, Theodore A. Some Observations on the Interrelationship of Sunlight, Aquatic Plant Life, and Fishes. 62nd Annual Meeting of the Am. Fish Soc. Baltimore. 1932.

8 Richards, F.A., and Corwin, N. Some Oceanographic Applications of Recent Determinations of the Solubility of Oxygen in Sea Water. Limnology and Oceanography. 1(4):263-267. October 1956.

9 Ruttner, Franz. (Translated by D.G. Frey and F.E.J. Fry.) Fundamentals of Limnology. Univ. of Toronto Press. pp. 1-242. 1951.

10 Truesdale, G.A., Downing, Al, and Lowden, G.F. The Solubility of Oxygen in Pure Water and Sea Water. J. Appl. Chem. 5(2):53-62. 1955.

This outline was prepared by H.W. Jackson, Chief Biologist, National Training Center, FWQA, Cincinnati, OH 45226.

WATER TEMPERATURE AND WATER QUALITY

I INTRODUCTION

A Temperature is the basic variable in water "climates".

1 Temperature, or the amount of thermal energy present, is originally of solar or cosmic origin. Biological processes acting over geologic time temporarily capture and store much energy in organic substance. The "fossil fuels" (oil, gas, and coal) which we burn today release solar energy captured in the geologic past, which but for man might not have been released until sometime in the geologic future. Most of the solar energy being captured today, is released probably today, with the possible exception of some unrecognized fraction which is proceeding into long term storage.

The release of atomic energy is of inorganic or cosmic origin, and the magnitude and significance of the additional thermal discharge to the environment has yet to be accessed.

One last observation is important before turning to the details of water temperature and water quality. While we are most critically occupied with the immediate or local impact of a concentration of thermal energy released at a given point in the environment (the excess or "waste" which man is unable to capture and entrain in his electric transmission lines), it should be remembered that of every ton of coal or pound of uranium burned as fuel, nearly 100% of the energy contained eventually finds its way into the general global environment. A small remaining fraction is rebound as chemical energy in some "product."

2 Direct solar radiation is the overriding contributor of thermal energy to all lands and waters.

a Total energy from insolation onto "spacecraft earth" is counterbalanced by the radiation of terrestrial energy into space. If the two do not exactly balance on an annual basis, the overall temperature (climate) of the earth will rise or fall.

b The annual climate or heat budget of a given body of water is determined by its geographic location (latitude elevation, etc.) interacting with local meteorological conditions, and other factors.

c There is, therefore, a natural or normal temperature regimen for any given body of water to which it will tend to return if disturbed by man.

d There is, also, a normal or characteristic community of aquatic organisms that will tend to persist. When the heat budget or climate of a body of water is changed, the fauna and flora change.

3 There is great diversity of opinion, even among knowledgeable people, as to the effects of thermal changes in waters. Some of the reasons for this follow:

a Only a continuously maintained temperature of 100° C could keep a surface water mass sterile. The question is therefore not: life or no-life; but rather: what kind of life is the objective?

b Aquatic life has received more attention than other water uses because the aquatic organisms cannot escape the water conditions.

c There are certain circumstances in which a modest rise in temperature might be considered to be beneficial as for example: keeping an area of a river or a harbor free of ice for navigation, or winter fishing. There has, also, been investigation of the use of warmed waters for certain aspects of aquaculture.

d It is, therefore, important in discussing the virtues and vices of thermal changes to clearly define or specify the objective or type of aquatic community in mind.

4 It is clear that the need for more and more power will continue into the foreseeable future (Table 1).

B Human activities which may modify receiving water temperatures include the following:

1 Logging and other land stripping activities which increase the rate of surface run-off and hence raise or lower temperatures of influent waters, depending on the season.

2 Removal of stream bank shade

3 Erosion which fills in stream bed and causes water to be spread in broad shallow layer, exposed to sun and air.

4 Release of cold waters from nypolimnion of deep reservoirs.

5 Withholding or augmenting flow by dam manipulation.

6 Release of relatively large volumes of high temperature wastewaters from power production and/or industrial processes.

II THERMAL ELECTRIC POWER PRODUCTION AS A STREAM WARMING ELEMENT

A Production of electric power by stream plants involves the wastage of considerable quantities of energy in cooling waters. Approximately 5000 BTU of heat are wasted for each kilowatt of electricity generated. This represents an efficiency of roughly 40%.

B It is estimated that approximately 80% of all energy required in the future will come from steam generating plants.

C Weirs and jetties help greatly in the dispersal of warmed waters, but must be carefully designed to each situation.

D As water temperature rises, its value as a coolant diminishes.

E Heat dissipation from a body of water which has been heated above its equilibrium temperature with the meteorological conditions follows Newton's Law of Cooling which states that the rate of cooling is proportional to the difference between the temperature of the body of water, and the equilibrium temperature for the given meteorological conditions. For example, an analysis of the Ohio River as at Cincinnati has shown that it would require over 200 miles to dissipate 99 + % of heat added (Figure 1).

III EFFECTS OF HEAT ON ORGANIC WASTE DISPOSAL

A Higher temperatures accelerate the rate of bacterial growth, the optimum temperature being in the range of 30° C (86° F).

1 As water temperatures approach this value, the rate of BOD thus approaches a maximum.

TABLE 1

MAXIMUM TEMPERATURES PROBABLY COMPATIBLE WITH THE WELL-BEING OF VARIOUS SPECIES OF FISH AND THEIR ASSOCIATED BIOTA IN °C

Temperature	Taxa
34 C	Growth of catfish, gar, white or yellow bass, spotted bass, buffalo, carpsucker, threadfin shad, gizzard shad
32 C	Growth of largemouth bass, drum, bluegill, crappie
29 C	Growth of pike, perch, walleye, smallmouth bass, sauger, California killifish, topsmelt
27 C	Spawning and egg development of catfish, buffalo, threadfin shad, gizzard shad, California grunion, opaleye, northern swellfish
24 C	Spawning and egg development of largemouthed bass, white and yellow bass, spotted bass, sea lamprey, alewife, striped bass
19 C	Growth or migration routes of salmonoids and for egg development of perch, smallmouth bass, winter flounder, herring
12 C	Spawning and egg development of salmon and trout (other than lake trout)
9 C	Spawning and egg development of lake trout, walleye, northern pike, sauger, and Atlantic salmon

2 If the waste assimilative capacity of a stream is being utilized based on a given stream temperature, and the temperature subsequently raised, the DO may drop so low as to produce fish kills and other nuisance conditions.

B Higher water temperatures may, also, lead to a higher concentration of bacteria pathogenic to man.

IV EFFECTS OF HEAT ON FISH AND OTHER AQUATIC LIFE

A Vulnerability of fish and other aquatic life to high temperatures represents a major restriction on the discharge of cooling water.

1 Involves duration of exposure as well as absolute thermal level.

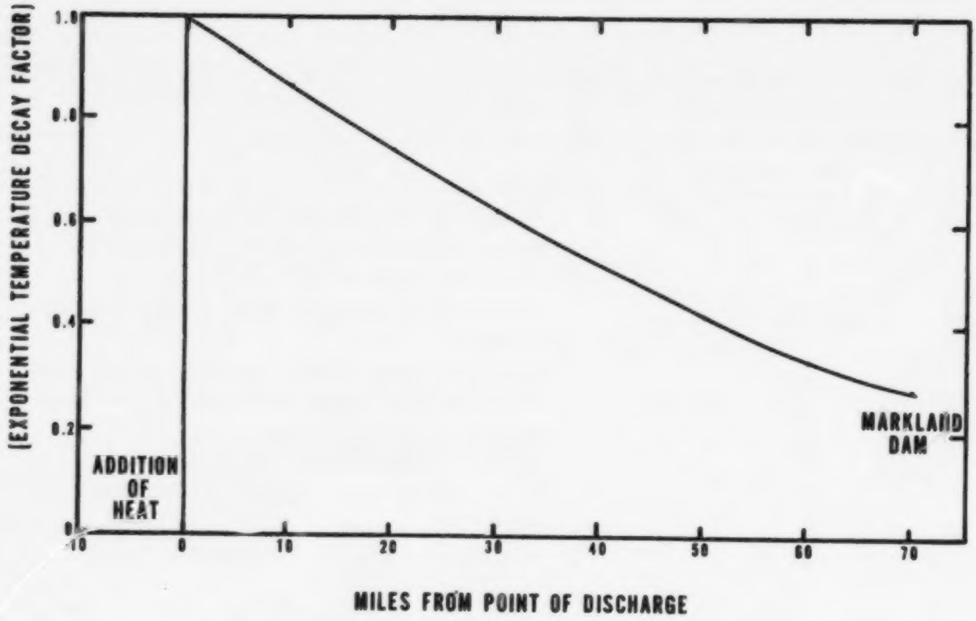
2 Sensitivity to toxic substances is increased.

3 Lower temperatures are required in winter than in summer.

B Factors contributing to the sensitivity of fish to heat

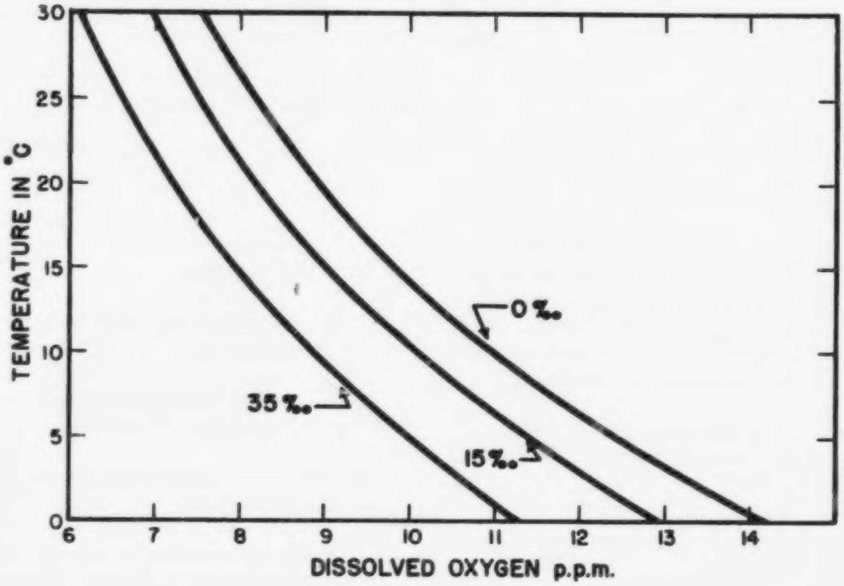
1 Oxygen solubility diminishes as temperature rises (Figure 2).

2 Oxygen requirements of aquatic life increase as temperature rises (Figure 3).



TEMPERATURE DROP THROUGH MARKLAND POOL
OHIO RIVER

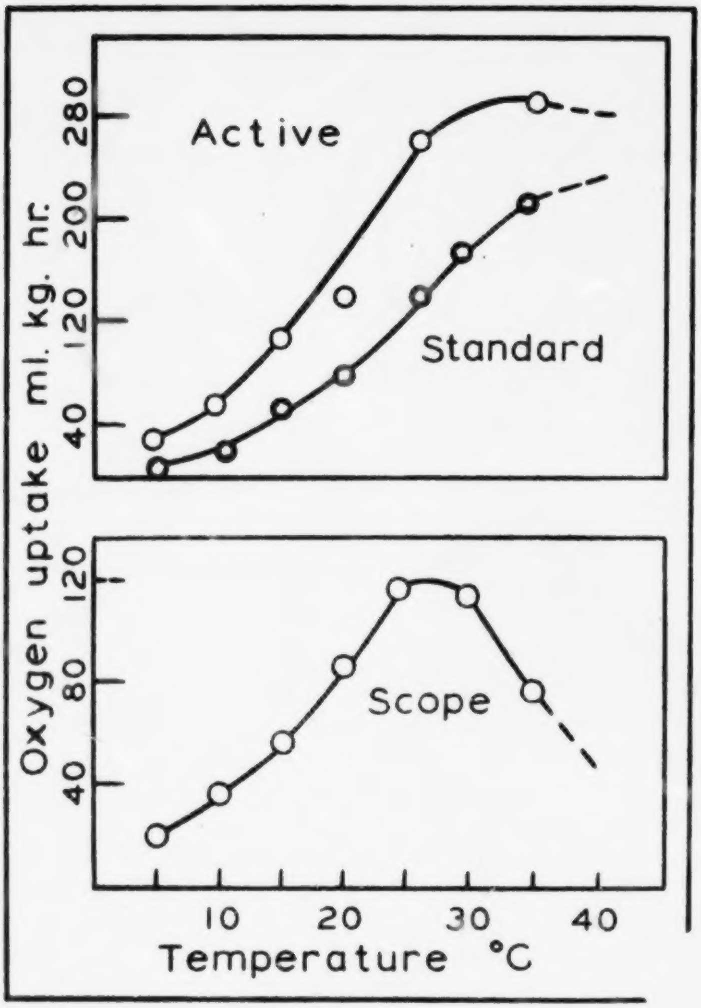
Figure 1



OXYGEN SOLUBILITY AT SELECTED SALINITIES

RICHARDS AND CORWIN, LIMNOLOGY AND OCEANOGRAPHY, 1956 BI.ECO.Sc.2.68

Figure 2

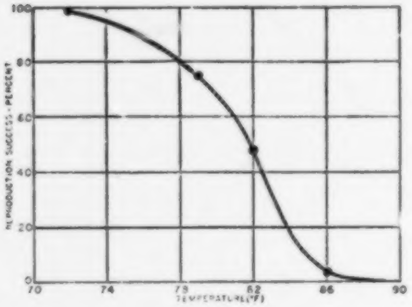


THE RELATION OF TEMPERATURE TO ACTIVE AND STANDARD METABOLISM IN YOUNG GOLDFISH OF AN AVERAGE WEIGHT OF 2 GM. From Fry and Hart (1948)

Figure 3

3 The sensitivity of aquatic organisms to temperature levels and changes varies with age, size, and size.

a A constant elevated temperature reduces the potential of fish to reproduce (Figure 4).



EFFECTS OF CONSTANT TEMPERATURE ON REPRODUCTION OF A MINNOW (*Pimephales promelas*)

Figure 4

b Different species have different preferred temperature ranges.

c Seasonal cooler temperatures are often essential to egg production and hatching, while warmer summer temperatures will promote faster growth after hatching, up to some limit of tolerance characteristic of the species.

4 Lethal high temperatures as determined in laboratory tests vary widely for different species, e.g. goldfish: 107.6° F, pink salmon: 75° F.

a Lethal temperatures differ at different times of the year, as well as for the different life history stages (Figure 5).

b This is analogous to a temperature of 50° F for man: in winter it feels "warm," in summer it is "cool."

5 Sudden changes in water temperature can be fatal to certain organisms, both fish and fish food organisms.

6 Acclimatization to higher temperatures is faster than to lower. Fish acclimated to warm water are rapidly killed when they swim into cold water. This implies that the sudden shutdown of a thermal discharge may be more detrimental than a continuous normal discharge.

7 Reduction in DO, increase in CO_2, or the presence of toxic materials reduces maximum tolerable temperatures.

8 Species can be eliminated at less than lethal temperatures by predators, parasites, or diseases which are less temperature-sensitive.

9 Some fish do not seem to be able to avoid killing hot waters, while others do.

10 Preferred temperature ranges in laboratory tests generally are somewhat higher than in field observations (Figure 6). This may be influenced by the demands of the natural environment for greater activity and hence a need for more oxygen (Figure 2, Table 1).

11 Temperature can act as a directive force in fish migration.

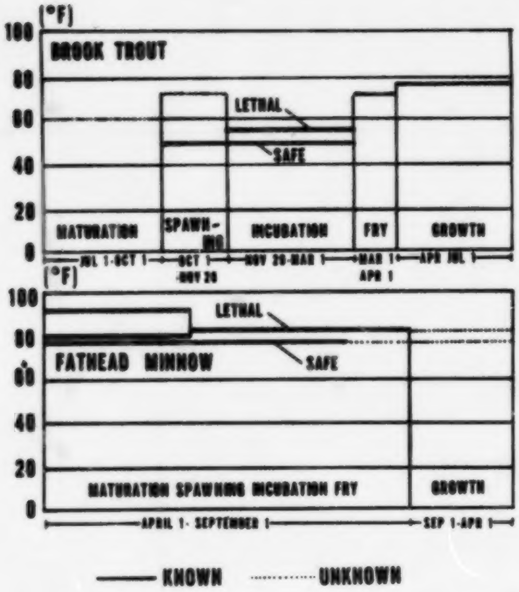
12 The exact physiological mechanisms of heat kill are not fully understood.

Fats rather than proteins seem to be the most critical substance.

a Some fish will die at temperatures of 65° F, lower than that at which proteins usually coagulate.

b Tropical (or heat-adapted) plants and animals often have fats with a higher melting point than arctic (or cold-adapted) organisms.

c Animals (such as goldfish) fed high melting point fats (e.g. beef) develop higher melting point body fats than those fed on low-melting fats (such as fish oil). They are in turn able to tolerate higher temperatures.



THERMAL TOLERANCE OF CRITICAL LIFE HISTORY STAGES

Figure 5

d Lethal temperatures seem to destroy fat-calcium relationships.

C Effects of Temperature on Fish Food Organisms

1 Species composition and abundance are affected in ways similar to the fishes as outlined above.

2 Warm waters encourage blue-green algae. Some can tolerate as high as 185° F for limited periods (Figure 7).

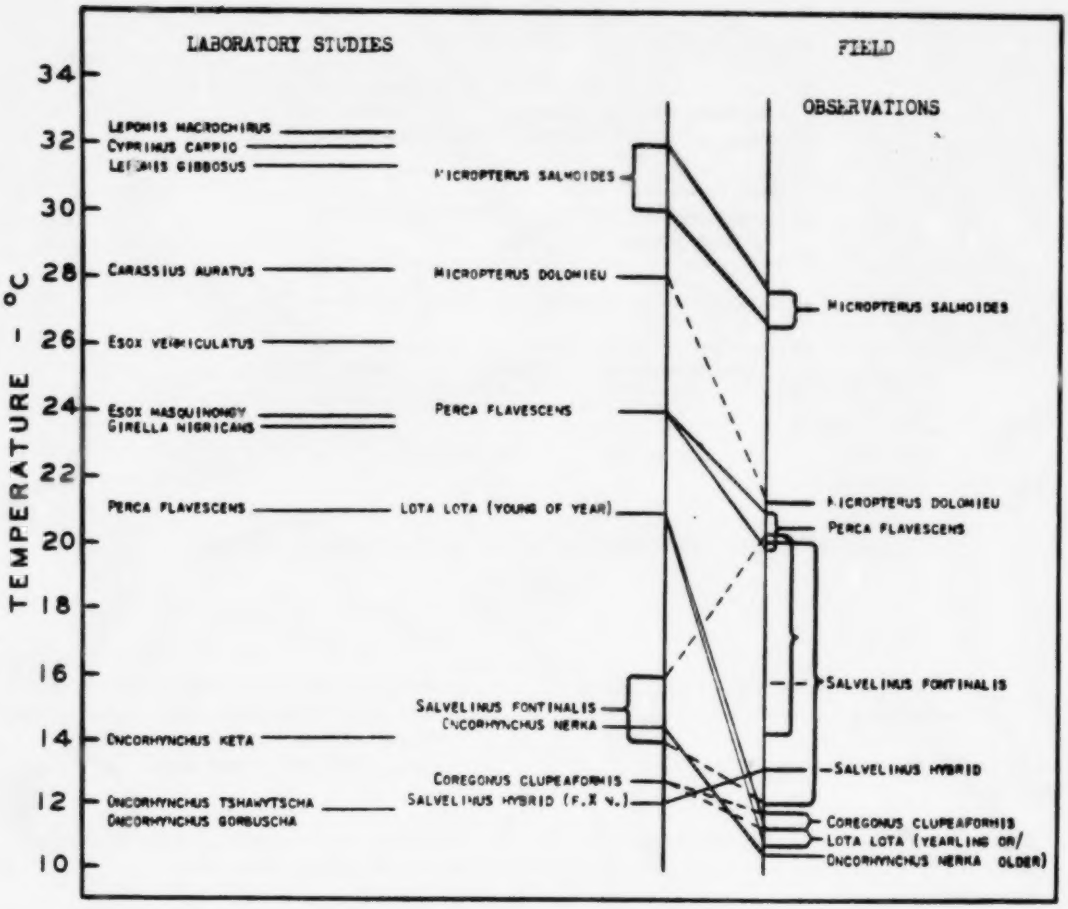
3 A temperature increase of 8° C stimulated photosynthesis in phytoplankton in one series of observations when ambient water temperatures were 16° C or cooler, but inhibited photosynthesis when natural waters were 20° C or warmer. The existence of a diurnal response to thermal stimulation was noted at 9:00 A.M.

4 Warmed waters speed up life cycles and encourage year round emergence of aquatic insects, often creating local nuisance conditions.

V MARINE, ESTUARINE, AND ANADROMOUS SPECIES

A The general principles of biotic responses to thermal conditions outlined above apply as well to salt water forms as to fresh.

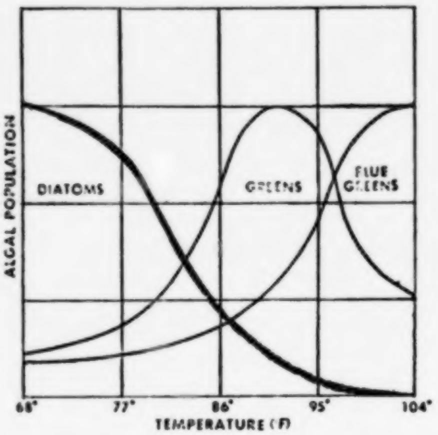
B Salmon do not feed during the spawning migration, hence higher temperatures may so increase their metabolic demands as to deplete their food reserves before spawning can occur. A thermal block at the mouth of a river (e.g. 21.1° C at the mouth of the Okawogan River in Washington) can prevent an entire spawning run.



Left. A comparison of various final preferenda as found by laboratory studies.

Right. A comparison of field observations with laboratory results for a number of species.

Figure 6



EFFECT OF TEMPERATURE ON TYPES OF PHYTOPLANKTON

Figure 7

1 The American Oyster Crassostrea Virginica may spawn, depending on its condition, at temperatures from 15 to 34° C, spawning being triggered by a rise in temperature.

2 The shore crab Carcides Maenas thrives, but does not breed at temperatures between 14 and 28° C. Breeding can only take place outside the heated area.

C Fish in the estuarine environment are more susceptible to temperature changes than those in fresh water. However, wider ranges of tolerance between species exist.

D Most shellfish (in the broad sense: mollusca and crustaceans) are relatively or highly stenothermal (unadaptable to rapid temperature changes). Some are stenothermal for one stage (e.g. spawning), and eury-thermal for others (e.g. growing).

Preliminary observation, also, indicates that heat stress may stimulate oysters to accumulate copper (as other stressful factors are known to do) without being a direct killing agent.

E The distribution of many benthic invertebrate organisms is temperature dependent (See Table 2).

ENVIRONMENTAL TEMPERATURE RANGES OF SOME MARINE INVERTEBRATES

Table 2

Taxa	Temperature range in ° C
American Oyster	4 - 34
European Oyster	0 - 20
Opossum Shrimp	0 - 31

F Observations in Miami, Florida indicate that the following groups of larger plants may show temporary or permanent changes following thermal discharge:

1 The sea grass Thalassia, an important habitat for invertebrates and stabilizes of the substrate.

2 Certain macro-algae

(Lurencia, Fucus, Laminaria, Macrocystis, Halimeda, and Acetabularia)

3 The phytoplankton (see Figure 7)

4 The epiphytic micro-algae

5 The benthic micro-algae

G The upper limits of thermal tolerance for two species of copepods from Chesapeake Bay were found to be near the normal temperature of the habitat during the summer. The addition of chlorine to the cooling water killed all copepods passing through the system at temperatures below the upper limits of thermal tolerance.

Dry weight of total estuarine epifauna production averaged 2.8 times greater in the discharge canal than in the intake area over a 5 year period in another study.

VI SUMMARY

The various environmental factors cannot be considered as isolated entities, organisms respond to the entire environment. Temperature criteria thus must be based on the requirements of the entire aquatic population, and on the life history requirements for different seasons of the year.

REFERENCES

1 Berger, Bernard B. Does Production of Power Pollute our Rivers? Power Engineering. March 1961.

2 Cavins, J. Jr. Effects of Increased Temperature on Aquatic Organisms Industrial Wastes. Vol. 1 (4): 150-152. 1956.

3 Clark, S.M. and Snyder, G.R. Timing and Extent of a Flow Reversal in the Lower Columbia River. Jour. Limn. of Ocean. Vol. 14. November 1969.

4 FWPCA, Water Quality Criteria Section III, Fish, Other Aquatic Life, and Wildlife. 1968.

5 FWPCA, Northwest Water Laboratory. Industrial Waste Guide on Thermal Pollution. Revised 1968.

6 FWPCA Presentations, ORSANCO Engineering Committee, Seventieth Meeting, Terrace Hilton Hotel, Cincinnati, Ohio. September 10, 1969.

7 Heibrun, L.V. Heat Death, Scientific American. pp. 70-75. April 1954.

8 Pennsylvania State of. Heated Discharges.... Their Effect on Streams Pub. No. 3, Div. San. Engr., Bur. Environmental Health, Dept. of Health. January 1962.

9 Trembley, F.J. Research Project on Effects of Condenser Discharge Water on Aquatic Life. Progress Report. Inst. of Research. Lehigh Univ. November 21, 1960.

10 Chesapeake Science. Proceedings of the 2nd Thermal Workshop of the U.S. International Biological Program. Solomons, Md. Vol. 10 (3-4). 1969.

This outline was prepared by H.W. Jackson, Chief Biologist, National Training Center, FWQA, Cincinnati, OH 45226

ECOLOGY OF POLLUTED WATERS:
EFFECT ON STREAM COMMUNITIES

I WATERS ARE POLLUTED WHEN WASTES INTERFERE WITH USES.

II FOR EVERY ACTION THERE IS A REACTION.

A Water cannot be pure H_2O because many elements are needed to produce desirable products such as fish, acceptable taste, chemical buffering.

B Anything in excess can become detrimental.

C To prevent problems, apply moderation with vigor!

III APPROACHING THE EVALUATION OF THE EFFECTS OF POLLUTION ON THE WATERWAY'S ECOSYSTEM.

A Assess Damages

B Ascertain Causes

C Advise on Corrective Needs

  1 How much!

  2 Not how!

IV NEEDS OF ORGANISMS ARE: Food, A Place to Live, Air to Breathe, A Nursery, Protection from adverse environmental factors and over predation. All are needed and all are interrelated.

V THE STREAM AS A SEWAGE TREATMENT FACILITY

(A saprophytic community = nurtured on non-living organic materials).

A Primary Treatment - Removal of Settleable and Floating Solids.

  1 Rats remove the floating solids.

  2 Worms and carp digest the settleable solids from sludge deposits.

B Secondary Treatment - Removal of Non-settleable and Dissolved Organic Materials Through Their Use as a Media for the Growth of Settleable Organisms and Flocs.

  1 Animal and bacterial slimes growing in streams remove organic nutrients, some colloidal materials and bacteria, for examples *Sphaerotilus* and *Leptomitus*, protozoans, and microscopic animals.

  2 Bacteria and large particulate materials may be consumed by filter-feeding organisms such as black flies, some caddisflies, and plankton feeding fishes.

C Tertiary Treatment - Especially Inorganic Nutrient Removal - Removal of Materials not Readily Removed by the Saprophytic System.

  1 Precipitation within the stream, for example iron (yellow boy).

  2 Growth of autotrophic algae and rooted vegetation removes inorganic nutrients from the water masses.

D Longitudinal distribution within the stream is the same as in a modern treatment facility bar screens (over hanging - tree branches and logs), comminuter (turbulence in riffles), primary → secondary → tertiary, sludge digestors (sludge deposits), etc.

E Problems within stream waste assimilation are somewhat analogous to problems with a treatment facility.

  1 Efficiency very poor until appropriate biota becomes established.

  2 Periodic organic overloading. Neither an aerobic or an anaerobic biological system has the opportunity to become fully acclimated.

  3 Slugs of toxic material. Destroys established biota and the system works poorly until biota reestablish themselves.

NOTE: You cannot bypass a stream.

F The waste waters will be "treated". Man cannot afford to have the treatment take place on a random basis within the waterways. It is dangerous to his health, welfare, economy, and resources. Treatment facilities confine the problems into a limited environment that can be regulated to achieve maximum efficiency.

VI THE COMPONENTS OF A STREAM COMMUNITY.

A Physical

B Chemical

C Biological

1 Reducers

2 Producers

3 Consumers

VII THE SAPROPHYTIC COMMUNITY CONTAINS AN EXCESS OF REDUCERS.

A Assets

1 Waste assimilation

B Debits

1 Creates taste and odor problems

2 Creates aesthetic problems and interferes with recreation

3 Alters chemical characteristics of water

4 Alters physical characteristics of water

VIII THE ALGAL COMMUNITY

A Exists in two forms Planktonic, and attached (Periphyton, Aufwuchs).

1 Periphyton predominant in shallow rivers and clear lakes.

2 Plankton predominant in large rivers, many lakes, and marine waters.

B Assets

1 Primary production of food utilized in food-chain.

2 Dissolved oxygen is a by-product of primary production (daylight hours).

3 Removes nutrients such as carbon (as carbon dioxide), nitrogen and phosphorus from the water mass.

C Debits

1 Has oxygen demand and produces carbon dioxide (hours of darkness).

2 Creates taste and odor problems.

3 Creates aesthetic problems and interferes with recreation.

4 When community dies becomes very strong organic load to be assimilated.

5 Altering of alkalinity and pH

IX THE FLOWERING AQUATIC PLANT COMMUNITY

A Assets

1 Shelter and nursery areas for many fishes

2 Habitat for fish-food organisms

3 Waterfowl food

4 Dissolved oxygen is by-product of primary production (daylight hours)

5 Removes nutrients

B Debits (Same as for Algal Community)

X THE BOTTOM ANIMAL COMMUNITY

A Assets

1 Major consumer of algae and organic detritus

2 Converts plant foods to animal life which serves as food for valuable predatory fishes.

B Debits

1 Mass emergence of insect species may be nuisance.

2 Some forms as adults (i.e. mosquitoes and black flies) are important disease vectors.

XI THE FISH COMMUNITY

A Assets

1 Aid in controlling insect and algal populations

2 Provide recreation

3 Support a food and by-product industry

B Debits - Minimal

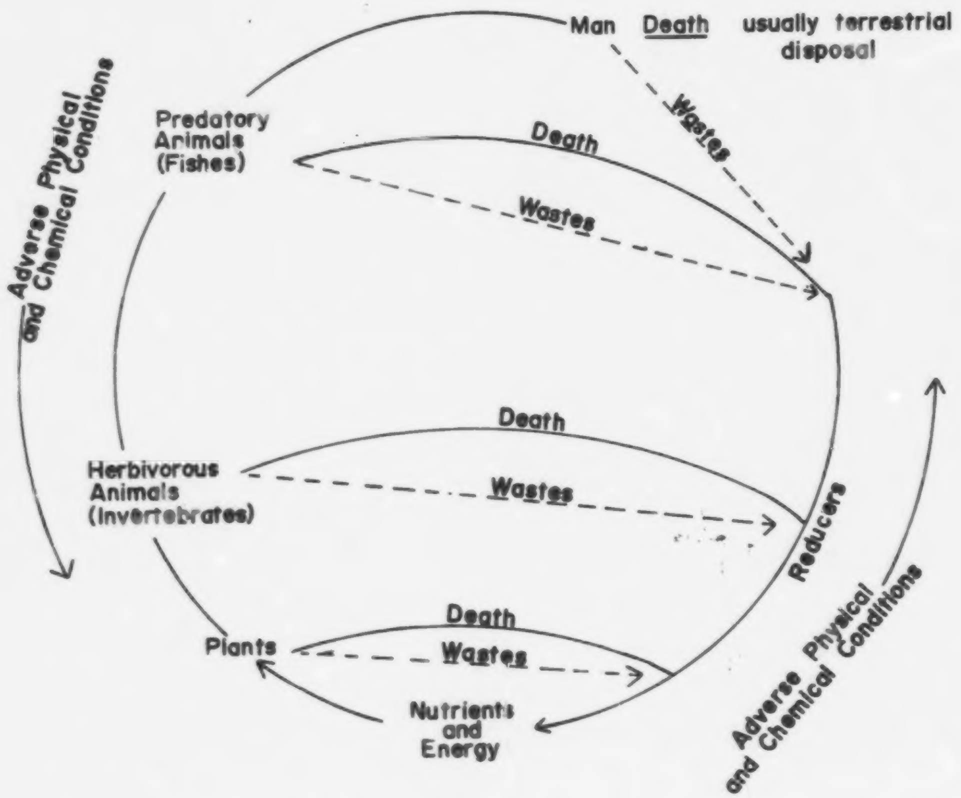
XII THE HUMAN COMMUNITY

A Assets?

B Debits - May defile waters

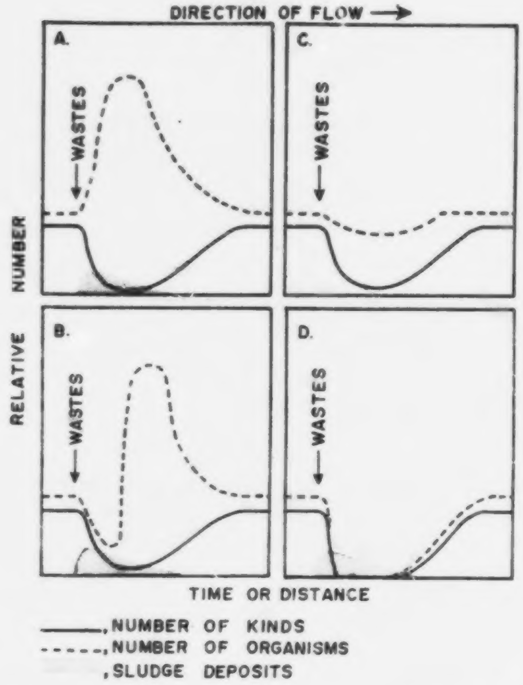
XIIV THE STREAM COMMUNITY AS A WHOLE (Figure 1)

Figure I. The Stream Community


Man
Death
usually terrestrial disposal
Wastes
Predatory Animals (Fishes)
Death
Wastes
Adverse Physical and Chemical Conditions
Herbivorous Animals (Invertebrates)
Death
Wastes
Reducers
Plants
Death
Wastes
Nutrients and Energy
Adverse Physical and Chemical Conditions

XIV EFFECTS OF ADVERSE PHYSICAL AND CHEMICAL CONDITIONS ON BIOTA (Figure 2)

Figure 2



Four basic responses of bottom animals to pollution. A. Organic wastes eliminate the sensitive bottom animals and provide food in the form of sludges for the surviving tolerant forms. B. Large quantities of decomposing organic wastes eliminate sensitive bottom animals and the excessive quantities of byproducts of organic decomposition inhibit the tolerant forms; in time, with natural stream purification, water quality improves so that the tolerant forms can flourish, utilizing the sludges as food. C. Toxic materials eliminate the sensitive bottom animals; sludge is absent and food is restricted to that naturally occurring in the stream, which limits the number of tolerant surviving forms. Very toxic materials may eliminate all organisms below a waste source. D. Organic sludges with toxic materials reduce the number of kinds by eliminating sensitive forms. Tolerant survivors do not utilize the organic sludges because the toxicity restricts their growth.

NOTE: Figure 2 discusses bottom animals. With slight modifications this system works also with other components of the ecosystem (i.e. fertilizers and algae, organic materials and the reducers, etc.).

A Destroys organisms. Beginning with most sensitive forms pollutants kill in order of sensitivity until the most tolerant form is the last surviving form. This results in a reduction of variety or diversity of organisms.

B The Numbers of Survivors Increase:

1 Competition and predation is reduced between forms.

2 When the pollutant is a food (plants, fertilizers, animals, organic materials).

C The Number of Survivors Decrease:

1 The material added is toxic, or has no food value.

2 The material added produces toxic conditions as a by-product of decomposition (for example large organic loadings produce an anaerobic environment resulting in the production of toxic sulfides, methanes, etc.)

D The effects may be manifest in combinations:

1 Of pollutants and their affects

2 Vary with longitudinal distribution in a stream

XV WHY A "COMPLETE" ECOSYSTEM (Figure 1)

If the system does not follow "through" to man,

A Man does not benefit, rather he suffers.

B The more complete the system the less the problems.

1 Each "higher" level exerts controls over "lower" levels.

2 Assets increase and debits decrease (Sections VIII, IX, X, XI & XIIV.)

REFERENCES

1 Bartsch, A.F., and Ingram, W.M. Stream Life and the Pollution Environment. Public Works, 90:7:104 (1959).

2 Blum, J. L. The Ecology of River Algae. Botanical Review, 22:5:291 (1956).

3 Erichsen Jones, J.R. Fish and River Pollution. Butterworth, London (1964).

4 Hynes, H.B.N. The Biology of Polluted Water. Liverpool University Press, Liverpool, England (1960).

5 Keup, L.E., Ingram, W.M., and Mackenthun, K.M. The Role of Bottom Dwelling Macrofauna in Water Pollution Investigations. PHS Publ. No. 999-WP-38 (1964).

6 Klein, L. River Pollution II. Causes and Effects. Butterworths, London (1962).

7 Mackenthun, K.M., and Ingram, W.M. Pollution and the Life in Water. PHS Publ. No. 999-WP-20 (1964).

8 Tarzwell, C.M. and Gaufin, A.R. Some Important Biological Effects of Pollution Often Disregarded in Stream Surveys. Purdue University Engineering Bulletin, Proc. 8th Ind. Waste Conf. 295 (1953).

This outline was prepared by Lowel E. Keup, Aquatic Biologist, Biological and Chemical Section, National Field Investigations Center, Federal Water Quality Administration, U. S. Department of the Interior

SIGNIFICANCE OF EUTROPHICATION

I INTRODUCTION

A Eutrophication may be defined briefly as enrichment (of the aquatic environment) leading to the production of aquatic life. It is part and parcel of the process of natural self-purification.

B Productivity is defined briefly as the ability of water (or land) to produce a crop of living things.

C A baseline assumption of the present discussion is the absence of toxicity.

II NATURAL EUTROPHICATION

A Eutrophication may occur naturally in the course of geologic time.

B The classic example is a "pot-hole" lake formed when a large block of glacial ice (which had been buried in sand and gravel) melted.

1 At the outset, it was a barren hole in a vast gravel plain filled with ice water.

2 Life quickly became established as bacteria and algae drifted in. The nutrient base at this time was the inorganic dissolved solids in water.

3 As time went on, dead organic matter began to accumulate on the bottom as ooze. Rooted vegetation crept in around the shore. Leaves, sticks, and other dead organic matter accumulated around the margins until a mat of sod and peat began to build out from the shores. This overgrowth continued until the water was closed over and bog resulted. Bog grew into solid soil and the lake disappeared forever.

4 The processes of eutrophication therefore led to the self-elimination of the lake by means of organic matter essentially produced within its own confines and the immediate environs.

C All natural eutrophication does not necessarily lead to the elimination of water basins; other geologic processes often intervene. But it is interesting to note that vast quantities of carbon, hydrogen, and oxygen have been immobilized in the earth's crust as coal and peat measures as the result of eutrophication and biological productivity in the Carboniferous (late Paleozoic). Streams may have a natural productivity resulting from materials leached from bed rock or other materials.

III EUTROPHICATION BY MAN

A Covert (Concealed) Eutrophication via Soil Seepage

1 This is a slow but sure route for much nutrient material deposited in or on the ground to reach open water.

2 A limited(?) and unknown amount of production occurs in the subterranean environment. This includes the growth of soil bacteria and other fungi, or animals, and does not generally result in the entrainment of additional energy content in the biomass (mass of organic substance).

3 Due to the generally low rate of water seepage through soil, visible eutrophication of open bodies of water by this route is likely to be slow to develop, and equally slow to dissipate, should the source be eliminated.

4 Examples could be cited from Florida to Washington and Maine to California. Sources of the nutrient are generally seepage from agricultural crop fertilization, or soil absorption from individual sewage disposal systems.

B Overt (Open) Eutrophication

1 Raw waste discharges of sewage, dairy wastes, food processing wastes, etc.

a Likely to be conspicuous, intermittent, and obnoxious.

b Often create nuisance zones in streams or lakes during which mineralization takes place.

c Environmental eutrophication cannot begin until mineralization has proceeded to a point where basic plant nutrients are available, although very heavy "consumer" growth (scavenger animals) may result from direct feeding on the waste itself.

2 Treated waste discharges

a Generally less environmentally traumatic than raw waste; nuisance zones less common.

b Conventional secondary treatment less damaging than primary treatment alone.

c Residual minerals and energy content still inevitably available for eutrophication.

3 Overt eutrophication generally more remediable and subject to control than covert.

a Waste flow is completely controllable (barring accidents), as compared to diffuse seepage through soil.

b The quantity of eutrophic material in a body of water at any given time is finite and degradable. Given time, without replenishment, it will be exhausted.

IV SIGNIFICANCE OF EUTROPHICATION

A A point of view such as a water quality objective, for example, is necessary for the evaluation of eutrophication.

1 Enrichment of a water supply reservoir is generally considered bad, as it usually leads to the development of blooms of plankton organisms causing tastes and odors, or the development of an anaerobic hypolimnion with accompanying H_2S and other problems.

2 Enrichment of a fishing lake is considered good to the point where maximum fish production can be obtained.

B Eutrophication exists in many degrees; a little may be good, too much may be bad.

C A little natural productivity (eutrophication) plus a little man-made productivity may lead to too much total productivity.

D Eutrophication is inexorable and inevitable. Once the basic ingredients have been dumped into a body of water, somewhere, sometime, they are sure to be assimilated by an organism and thus contribute to new growth. Burial in a sludge bank or discharge on a flood simply delays the result in time or changes the location.

E Deliberately encouraged, eutrophication may constitute a final stage in treatment.

V CONCLUSION

Eutrophication is neither good nor bad, but thinking makes it so! (Apologies to Shakespeare)

REFERENCE

Stewart, Kenton M. and Rohlich, Gerald A. Eutrophication - A Review. Publication No. 34, California State Water Quality Control Board, p 188. (1967)

This outline was prepared by H. W. Jackson, Chief Biologist, National Training Center, FWQA, SEC, Cincinnati, OH 45226

SECTION II

WATER QUALITY POLICY AND CRITERIA

	Outline Number
Guidelines for Establishing Water Quality Standards for Interstate Waters	8
Water Quality Standards - Pacific Northwest States	9
Water Quality Criteria - State of Washington	
Idaho and Montana Criteria for Waste Treatment and Pollution Control	
State of Oregon Water Quality Policy and Sewerage Works Design Criteria	
Control and Prevention of Pollution from Federal Installations	10

8-1-a

UNITED STATES DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

GUIDELINES FOR ESTABLISHING WATER QUALITY STANDARDS FOR INTERSTATE WATERS

(Under the Water Quality Act of 1965. Public Law 89-234)

May, 1966

The Water Qaulity Act of 1965 amended the Federal Water Pollution Control Act to provide for establishment of water quality standards for interstate waters. In the absence of State action, such standards will be adopted by the Secretary of the Interior under procedures set forth in the Act.

Standards adopted by a State will become the standards applicable if:

1 The Governor, or water pollution control agency, files by October 2, 1966, a letter of intent that the State, after public hearings, will, before June 30, 1967, adopt a
a) water quality criteria applicable to interstate waters or portions thereof within the State, and
b) a plan for the implementation and enforcement of the criteria; and

2 The State subsequently adopts such criteria and plan; and

3 The Secretary determines that the State criteria and plan are consistent with the purposes of the Act, i.e., "...to enhance the quality and value of our water resources and to establish a national policy for the prevention, control, and abatement of water pollution".

It is the position and purpose of the Federal Water Pollution Control Administration to encourage and support the States in establishing their own standards. The guidelines that follow are presented to assist the States in the development of the required water quality criteria and the plan for the implementation and enforcement thereof, and to delineate factors which will be considered in the Secretary's determination of whether the criteria and plan are consistent with the purposes of the Act.

GUIDELINES IN THE ACT AND ITS LEGISLATIVE HISTORY

First consideration should be given to the substantial guidelines on Congressional intent and purpose in establishing the water quality standards requirements that are contained in the Federal Water Pollution Control Act, as amended by the Water Quality Act of 1965, and in its legislative history:

1 "Standards of quality established pursuant to this subsection shall be such as to protect the public health or welfare, enhance the quality of water, and serve the purposes of this Act. In establishing such standards, the Secretary, the Hearing Board, or the appropriate State authority, shall take into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, agricultural, industrial and other legitimate uses." (Section 10(c)(3) of the Act)

2 "The discharge of matter into such interstate waters, or portions thereof, which reduces the quality of such waters below the water quality standards established under this subsection (whether the matter causing or contributing to such reduction is discharged directly into such waters or reached these waters after discharge into tributaries of such waters), is subject to abatement in accordance with the provisions of..."the Act. (From Section 10(c)(5) of the Act)

This outline is a copy of an official U.S. Government publication.

3 "Economic, health, aesthetic, and conservation values which contribute to the social and economic welfare of an area must be taken into account in determining the most appropriate use or uses of a stream. There ought to be a constant effort to improve the quality of the water supply, it being recognized that the improvement of the quality of water makes it available for more uses." (Senate Report No. 10 on the Federal Water Pollution Control Amendments of 1965, 89th Congress, 1st Session)

4 "Water quality standards would provide an engineering base for design of treatment works by municipalities and industries. Such standards would enable municipalities and industries to develop realistic plans for new plants or expanded facilities, without uncertainties about waste disposal requirements on interstate waters." (Senate Report No. 10, as above)

5 "Water quality standards are not designed for use primarily as an enforcement device; they are intended to provide the Secretary and State and local agencies with additional tools for objective and clear public policy statements on the use or uses to which specific segments of interstate waters may be put. Their principal objective is the orderly development and improvement of our water resources without the necessity of adversary proceedings which inevitably develop in enforcement cases." (Senate Report No. 10, as above)

6 "The Committee must re-emphasize its intent that water quality standards are not designed to "lock in" present uses of water or to exclude other uses, not now possible. The standards are not a device to insure the lowest common denominator of water quality but to enhance the quality and productivity of our water resources." (Senate Report No. 10, as above)

7 "The Committee intends that water quality standards should be applied on the basis of the water quality requirements of present and future uses of a stream or section of a stream, after due consideration of all factors and variables involved. (Senate Report No. 10, as above)

POLICY GUIDELINES

No one has the right to pollute. As President Johnson expressed it when he signed into law the Water Quality Act of 1965, "No one has a right to use America's rivers and America's waterways that belong to all the people, as a sewer. The banks of a river may belong to one man or one industry or one state, but the waters which flow between those banks should belong to all the people."

In support of the President's position, the specific provisions of the Water Quality Act of 1965, and expressions of policy by the Congress in enacting that legislation, the following additional policy guidelines are set forth:

1 Water quality standards should be designed to "enhance the quality of water." If it is impossible to provide for prompt improvement in water quality at the time initial standards are set, the standards should be designed to prevent any increase in pollution. In no case will standards providing for less than existing water quality be acceptable.

2 No standards of water quality will be approved which provide for the use of any stream or portion thereof for the sole or principal purpose of transporting wastes.

3 Water quality criteria should be applied to the stream or other receiving water or portions thereof. The criteria should identify the water uses to be protected and establish limits on pollutants or effects of pollution necessary to provide for such uses. Numerical values should be stated for such quality characteristics where such values are available and applicable. Where appropriate, biological or bioassay parameters may be used. In the absence of appropriate numerical values or biological parameters, criteria should consist of verbal descriptions in sufficient detail as to show clearly the quality of water intended (e.g., "substantially free from oil").

4 The measure of time period and limiting values which will govern for purposes of the criteria should be defined (e.g., annual arithmetic mean concentration, single daily maximum concentration). Where appropriate, the specified recurrence and duration of the accepted design stream flow should be defined (e.g., 25-year recurrence of minimum low flow of 10-day duration).

5 Water quality criteria should be accompanied by a description of present water quality and uses, together with uses expected in the future and the water quality required to make these uses possible. The water quality standards proposed by a State should provide for:

a Potential and future water uses as well as the present intended use and uses;

b The upgrading and enhancement of water quality and the use or uses of stream or portions thereof that are presently affected by pollution;

c The maintenance and protection of quality and use or uses of waters now of a high quality or of a quality suitable for present and potential future uses.

6 The plan for implementing and enforcing the water quality criteria should be submitted in sufficient detail to describe the nature of the actions to be taken to achieve compliance, a time schedule for such compliance, the controls and surveillance for measuring compliance, and the enforcement authority and measures for ensuring compliance. It is recognized that there are a number of ways that the water quality standards can be effectively implemented and enforced by the States; achievement of the purposes of the Act, rather than the methods by which this is done, is paramount.

7 The plan should include consideration of all relevant pollutional sources, such as municipal and industrial wastes, cooling water discharges, irrigation return flows, and combined sewer overflows.

8 No standard will be approved which allows any wastes amenable to treatment or control to be discharged into any interstate water without treatment or control regardless of the water quality criteria and water use or uses adopted. Further, no standard will be approved which does not require all wastes, prior to discharge into any interstate water, to receive the best practicable treatment or control unless it can be demonstrated that a lesser degree of treatment or control will provide for water quality enhancement commensurate with proposed present and future water uses.

9 Public hearings are required to be held by States establishing standards in accordance with the provisions of the Act.

A summary of each public hearing, accompanied by certification as to notice and conduct of such public hearing in conformity with procedures provided therefor, should be provided the Secretary. The summary should adequately advise him of:

a The waters which were the subject of the public hearing;

b The interests and interest groups represented, including those in downstream or adjacent States which would be affected by the standards;

c The views expressed on water quality and water uses by the various interests and interest groups;

d Statistical data, reports and other information submitted in support of statements, views, and positions expressed at the hearing, including those provided by the State or States holding the hearing.

When necessary to the Secretary's determination that the State criteria and plan are consistent with the purposes of the Act, a full transcript of the hearing and supporting data will be requested.

In the review of the hearing record to determine whether the State criteria and plan are consistent with the purposes of the Act, attention will be given to the extent to which there was expression of views by conservation, civic, recreation, agricultural, industrial and planning interests, as well as by Federal, State, interstate and local agencies. Particular attention will be given to the extent to which there was opportunity for participation by interests downstream or adjacent States which would be affected by the standards.

10 State standards will be reviewed in terms of their consistency and comparability with those for affected waters of downstream or adjacent States. Coordination is encouraged among States to assure such consistency.

11 The use or uses of the waters concerned, the water quality criteria to provide for such use or uses, and the plan for implementing the water quality criteria should be in conformity with any comprehensive water pollution control program developed pursuant to Section 3 of the Federal Water Pollution Control Act, as amended; should encompass any remedial program recommended by the Secretary as a result of an enforcement action taken under Section 10 of the Act; and should be revised to reflect any recommendations resulting as such programs and actions develop.

12 To meet the goals established by the Act, water quality standards must be adequate to protect and upgrade water quality in the face of population and industrial growth, urbanization, and technological change. In accordance with the provisions of the Act, it is anticipated that after the intial setting of standards, periodic review and revision will be required to take into account changing technology of waste production and waste removal and advances in knowledge of water quality requirements developed through research.

WATERS TO WHICH STANDARDS PROVISIONS APPLY

Water quality standards, under Section 10 (c)(1) of the Act, are to be established for, and made applicable to, interstate waters or portions thereof within the State.

1 The term "interstate waters," as defined in Section 13(e) of the Act,

means all rivers, lakes, and other waters that flow across or form a part of State boundaries, including coastal waters.

2 Within this definition, waters that flow across or form a part of State boundaries are subject to the provisions of Section 10(c)(1) of the Act.

3 Waters that flow across or form a part of the international boundary between a State and a foreign country are interstate waters within the meaning of the definition provided in Section 13(e) of the Act and similarly subject to the provisions of Section 10(c)(1) of the Act.

4 Coastal waters subject to the provisions of Section 10(c)(1) of the Act are the ocean waters along straight coasts, the waters along indented coasts which are subject to the ebb and flow of the tides, and the waters of the Great Lakes.

5 As noted above, the definition of "interstate waters" is in terms of water bodies -- "rivers," "lakes" and "other waters" -- and is not limited to only those portions of these water bodies at the point at which they flow across or form a part of State boundaries. In effect, therefore, water quality standards are to be established for and made applicable to the entire stretch of the interstate waters within a State.

6 Tributaries of interstate waters, which are not in themselves interstate waters, are not subject to the requirements of subsection 10(c)(1) of the Act. However, it is important to note that the discharge of any matter into such tributaries which reaches interstate waters and reduces the quality of such interstate waters below the established water quality standards is subject to abatement under Section 10(c)(5) of the Act.

COOPERATIVE ASSISTANCE

Within the limits of its resources, the Federal Water Pollution Control Administration will assist the States in developing their water quality criteria and plans upon request.

1 Requests for technical assistance and other information should be directed to the appropriate Regional Director of the Administration.

2 In addition, the Administration will establish national technical committees, one for each major water use defined in the Act, to review scientific findings on water quality requirements for each specific use and to advise the Secretary concerning this. Persons scientifically and technically qualified will be invited to serve. The technical committees will review and update these reports periodically to reflect new information. The findings of these committees, subject to review and approval by the Secretary, will serve as guides for approving water quality criteria and subsequent revisions thereof. These findings will be provided to the States as they become available.

3 The Administration has long-term water quality requirements research underway, and this will be accelerated. The results of this research will be made available as standards are revised, enforcement actions are taken, and programs of water quality enhancement progress.

4 The Administration encourages and will support cooperative State-Federal activities in connection with any State water quality standards implementation and enforcement plan. Initial discussions should be with the appropriate Regional Director.

WATER QUALITY CRITERIA - STATE OF WASHINGTON

I HISTORY

Federal Clean Water Act of October 1965

A Required Water Quality Standards Be Established

- 1 Included all Coastal and Interstate Waters
- 2 Deadline of June 30, 1967

B Guidelines - No one has the right to pollute.

- 1 Must preserve or enhance water quality
- 2 All wastes amendable to treatment must be treated.
- 3 All water uses must be considered - present and future.
- 4 Must have a plan of implementation, monitoring and enforcement
- 5 Public Hearings must be held
- 6 Must coordinate with other states to achieve compatible standards.

II WASHINGTON'S PLAN

A Improve Existing Law

- 1 Definition of pollution
- 2 Streamlined enforcement
- 3 Established damage recovery
- 4 Drainage basin planning

B Proposed a Regulation and Plan

- 1 Decided to go to stream classification
  - a Classification based on use and quality
    - 1) Uses - water supply
    - 2) Stock watering - wildlife
    - 3) Recreation and esthetics
    - 4) Navigation
    - 5) Fish and shellfish
- 2 Four classifications

AA	Extraordinary
A	Excellent
B	Good
C	Fair

C Class AA Extraordinary - good for all uses including domestic water supply

- 1 Coliform

  50 - Fresh Water
  70 - Marine
  Not more than 10% exceeding 230

- 2 Dissolved oxygen

  9.5 - Fresh Water
  7.0 - Marine

- 3 Temperature

  60°F - Fresh Water
  55°F - Marine

  Allows 6° increase at 37° and increase decreases to 0 at upper limit.

- 4 pH

  6.5 - 8.5 Fresh Water
  7.8 - 8.5 Marine

  Induced variation less than 0.1.

- 5 Turbidity

  5 JTU

- 6 Toxic, radioactive and other - less than public health significance.
- 7 Esthetic - shall not offend the senses of sight, smell, touch and taste.

D Class A Excellent - meets requirements for substantially all uses (Same as AA)

- 1 Coliform - fresh water 240 with less than 20% exceeding 1000

  Marine - 70 with less than 10% over 230

- 2 Dissolved Oxygen

  8.0 - Fresh Water

  6.0 - Marine

3 Temperature

65°F - Fresh Water
61°F - Marine

Allows slightly higher upper limit than AA. Same increase at lower temperatures.

4 pH

6.5 - 8.5 Fresh Water
7.8 - 8.5 Marine

Induced variation less than 0.25.

5 Turbidity - not over 5 JTU

6 Toxic - radioactivity

Less than public health significance or causing acute or chronic toxic condition to biota.

7 Esthetic

Shall not offend sense of sight, smell, taste or touch excluding natural sources.

E Class B Good

Meets requirements for most uses - these include all except domestic water supply.

1 Coliform

1000 with less than 20% over 2400

2 Dissolved oxygen

6.5 - Fresh Water
5.0 - Marine

3 Temperature

70°F - Fresh Water
66°F - Marine

4 pH

6.5 - 8.5 Fresh Water
7.8 - 8.5 Marine

Induced variation less than 0.5 units.

5 Turbidity - less than 10 JTU over natural.

6 Toxic, radioactive

Shall not affect characteristic uses or be toxic to aquatic biota or public health.

7 Esthetic

Shall not affect typical water uses or taint fish flesh.

F Class C Fair

Meets requirement of selected and essential uses - restricted to navigation, boating, fish passage.

1 Coliform

Shall not exceed median value of 1000

2 Dissolved oxygen

5.0 - Fresh water
4.0 - Marine

Not less than 50% saturation.

3 Temperature

75°F - Fresh water
72°F - Marine

4 pH

6.0 - 9.0 Fresh water
7.0 - 9.0 Marine

Less than 0.5 unit induced variation.

5 Turbidity - not more than 10 JTU over natural.

6 Toxicity, radioactive - no effect on public health, aquatic biota or restrict characteristic uses.

7 Esthetic - not effected by obnoxious wastes, slimes, aquatic growths or taint flesh of edible fish.

G River and Coastal Water Classification

1 Basically either AA or A

B and C only in special circumstances as areas of high waste discharge in relation to volume of water - especially in low flow areas.

2 May be lower class because of natural conditions not meeting higher standards especially temperature.

H General Consideration

1 Higher class shall prevail at line between classes.

2 Brackish water if salinity (salt content) is over:

  1 part per thousand marine DO values shall apply

  10 parts per thousand marine coliform values shall apply

3 Dilution area at outfall described - limited size only applies if facility or plans approved or for industry if a permit is issued.

4 In no case will water quality be lowered to the limits of a standard.

I Implementation and Enforcement Plan

1 Basically sets treatment requirements and time schedules to comply

  a Secondary treatment

  Exception if discharge to salt water and can be demonstrated that lesser treatment will adequately protect water quality.

  b Five-year maximum to get units into operation

  Exception is storm water and infiltration. Study and plan must be completed in five years.

2 Miscellaneous sources

  a Soil erosion

  b Irrigation return water

  c Boats and marinas

  d Cooling water

  e Impoundments

  f Feed lots

  g Log storage

  h Dredging

  Plan requires study of these to determine effects and what controls if any are needed and can be implemented.

3 Monitoring program

  a Municipal

  b Industrial

  c Effluent surveys

  d Special surveys

  e Routine water quality sampling

4 Enforcement

  a Plan approval for domestic

  b Permits for industrial

  c Damage recovery

  d Criminal penalty

IDAHO AND MONTANA CRITERIA FOR WASTE TREATMENT AND POLLUTION CONTROL

I INTRODUCTION

II WATER QUALITY STANDARDS

A Idaho

(Approved except for Bear River Basin)

1 All interstate waters covered by water quality standards.

2 Policy of Idaho State Board of Health on waste treatment and pollution control.

a "…. notwithstanding the water quality standards……, the best practicable treatment shall be provided….."

b The degree of treatment shall be determined in each instance, considering potential downstream uses, size and nature of stream flow, quantity and quality of wastes, and presence of other pollution.

c Secondary treatment with disinfection or the equivalent will be required for all new domestic waste discharges.

3 Stream quality standards

B Montana

Approval pending

C Present State Water Quality Standards

1 Adopted June 1967; Revised OAS 334, 11-005 through 11-070

a Definitions

Sewage
Industrial waste
Wastes
Pollution
Waters of the state
Marine waters
Estuarine waters
Fish and other aquatic life
Standards

b Highest and best practicable treatment and control

c Maintenance of standards of quality; determination of waste treatment requirement

1) Uses, present or future, of the receiving stream

2) Size and nature of flow of the receiving stream

3) Quantity and quality of wastes to be treated

4) Presence or absence of other waste or pollution sources on the same watershed.

NOTE: All sewage shall receive a minimum of secondary treatment or equivalent (equal to at least 85% removal of 5-day biochemical oxygen demand and suspended solids) and shall be effectively disinfected before being discharged into any public waters of the state.

2 General water quality standards

a Water Quality Standards as adopted July 1, 1967 pertain to stream quality as a result of waste discharges.

General standards--apply to all state waters

Specific standards--apply to specific interstate waters as required by Section 10 (c) of the "Federal Water Pollution Control Act."

b Implementation plan

1) Outlines in detail the facilities or actions needed to achieve compliance with the standards,

3 All streams (interstate and intrastate) are classified and covered by the standards.

4 The minimum treatment required for domestic sewage shall be secondary treatment or its equivalent with the understanding that properly designed and operated sewage lagoons will meet this requirement.

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III WASTE TREATMENT SYSTEM CRITERIA

A Idaho

1 Package plants

2 Lagoons

3 Chlorination

4 Effluent to streams

B Montana

1 Package plants

2 Lagoons

3 Chlorination

4 Effluent to stream

STATE OF OREGON
WATER QUALITY POLICY AND SEWERAGE WORKS DESIGN CRITERIA

I WATER QUALITY STANDARDS

A State Standards - adopted 1938

- 1 ORS 449.077 - amended July 1, 1967 "Declaration of policy on water pollution"
- 2 ORS 449.080 - amended July 1, 1967
  - a Subsection 2 - authorizes establishment of minimum requirements for "disposal of wastes and minimum requirements for operation and maintenance of sewerage systems, treatment works and disposal systems..."
  - b Subsection 3 - authorizes the Sanitary Authority to formulate and adopt water quality standards in the state.
- 3 ORS 449.086 - amended July 1, 1967 Specific authorization for the Sanitary Authority to set standards of water quality for the public waters of Oregon.

B Federal Involvement

- 1 Section 10 (c) Federal Water Pollution Control Act - 1956 "Enforcement Measures Against Pollution of Interstate or Navigable Waters" - amended by the Water Quality Act of 1965 (89-234).
  - a States must by June 30, 1967, adopt water quality criteria for interstate waters or portions of interstate waters within the state.
  - b Plan for implementation and enforcement of such standards must also be adopted by the states by June 30, 1967.

  A time schedule for compliance, controls and surveillance for measurement of compliance and measures to be taken to ensure compliance.
- 2 Means of ensuring compliance
  - a Waste discharge permit
  - b Sewerage works plan review

II POLICY AND CRITERIA FOR SEWERAGE WORKS

A Laws relating to plan review - ORS 449.080 Powers and duties of Sanitary Authority in relation to water pollution

Section 2 - ORS 449.150
Prohibits discharge of wastes into public waters without state-approved treatment.

ORS 449.245
Approval of State Board of Health required for all sewerage projects serving more than 5 families or 50 people.

ORS 449.395
Approval of Sanitary Authority required for all sewerage projects serving more than 25 families or 100 persons.

B General Policy

- 1 All reports or plans and specifications for sewerage works projects must be designed, or approved and stamped by a professional engineer, registered in the State of Oregon under ORS 672.
- 2 The preparation of plans and specifications for all projects of major significance, including interceptor sewers, sewage pumping stations, and sewage treatment plants should be preceded by a preliminary engineering report resulting from a comprehensive study of the proposed project by a qualified professional engineer. It is usually of value to confer with staff members of the Sanitary Authority frequently during the preliminary study so as to facilitate final approval of the report after it is submitted.
- 3 Plans and specifications must be prepared by or approved and stamped by a registered professional engineer and must be consistent with the basic findings of the preliminary report.
- 4 The preliminary engineering report should be submitted to the Sanitary Authority as soon as possible after completion of the study so that a determination may be made as to the desirability of the proposal and the conformance of the proposal of water quality standards of the state.

5 Plans and specifications must be submitted to the Sanitary Authority for review and approval prior to construction in conformance with ORS 449.245 and 449.395.

6 The engineer whose stamp appears on the plans and specifications shall be responsible for the construction of the project in accordance with the approved plans and specifications and shall certify thereto, upon the completion of the project.

C Specific State Design Criteria

1 Sewer design criteria

2 Aerobic digestion - package plant design criteria

3 Lagoon design criteria

4 Ten States Standards for Sewage Treatment Plant Design

This outline was prepared by Patrick D. Curran, Senior Sanitary Engineer, Oregon State Sanitary Authority.

CONTROL AND PREVENTION OF POLLUTION FROM FEDERAL INSTALLATIONS

I HISTORY OF DEVELOPMENT OF FEDERAL REQUIREMENTS FOR CONTROL OF WASTES FROM FEDERAL INSTALLATIONS

A PL 845 - 1948 - 1953, Executive Order by President Truman

B PL 84-660 - 1956

1 Amended (PL 87-88) 7/20/61, "FWPCA Act Amendments of 1961," Executive Order by President Kennedy

2 Amended (PL 89-234) 10/2/65, "Water Quality Act of 1965," Executive Order 11258, 11/17/65, and Executive Order 11288, 7/2/66, by President Johnson

3 Amended (PL 89-753) 11/3/66, "Clean Water Restoration Act of 1966."

II IMPLEMENTATION OF FEDERAL LEGISLATION PERTAINING TO CONTROL OF WASTES FROM FEDERAL INSTALLATIONS. (SEE APPENDIX FOR COPIES OF LAW, EO, AND GUIDELINES).

A Section 11 of the Federal Water Pollution Control Act as Amended (PL-84-660) has the following opening statement: "It is hereby declared to be the intent of the Congress that any Federal department or agency having jurisdiction over any building, installation, or other property shall, insofar as practicable and consistent with the interests of the United States and within any available appropriations cooperate with the Department of the Interior, and with any State or interstate agency or municipality having jurisdiction over waters into which any matter is discharged from such property, in preventing or controlling the pollution of such waters."

B Implementation of this Section is through EO 11288 and Guidelines which have been developed for use of FWPCA and all Federal agencies.

III BASIC POLICY PROVISIONS OF EO 11288

A Congress has expressed its intention that all Federal agencies cooperate with the Department of the Interior and with any State or interstate agency or municipality in preventing or controlling water pollution.

The Federal Government is rightly expected to provide an example to the Nation in pollution control. New demands for pollution control cannot be made on State and local governments or on private industry without putting the Federal house in order. The President, in discussing "Programs for Controlling Pollution and Preserving Our Natural and Historical Heritage," has stated "We will take the necessary steps this year (1966) to insure that Federal facilities do not contribute to the deterioration of our water and air."

EO 11288, in effect, requires all Federal agencies to step up their efforts in the nationwide effort against water pollution. Although water pollution from Federal activities is only a small part of the total water pollution problem, the Order is designed to insure that the Federal government will provide the leadership in preventing and abating water pollution in the United States.

B Primary responsibility for carrying out provisions of EO 11288 is a responsibility of the FWPCA. To make this coordination effective, Guidelines for implementation have been developed.

C State criteria are minimum criteria and requirements of FWPCA.

D States are not bound by EO 11288 or its Guidelines or interdepartmental agreements pertaining to implementation of the EO.

IV IMPLEMENTATION GUIDELINES

A Guidelines have been developed for implementation of Executive Order 11288.

1 In a news release August 16, 1967, Secretary of the Interior, Stewart L. Udall issued the "Guidelines" and called upon all Federal agencies to put their own houses in order in the Nation's fight against water pollution and re-emphasized the responsibility of the Federal Government to set the example and provide the leadership to improve water quality throughout the United States.

2 The Guidelines were prepared by the FWPCA, with the cooperation of the other Executive agencies and departments. Some 26 Federal agencies participated in a review and submitted comments prior to their final adoption.

B Purpose

1 In essence, the Guidelines:

a Outline the procedure an agency or department planning a new facility should follow as far as pollution control is concerned.

b Require consultation between the FWPCA and other Federal departments or agencies on existing pollution problems.

c Provide for the submission and review by the Secretary of the Interior of any Federal plans for water resource development projects to determine their impact on water quality.

d Spell out general standards for waste treatment.

C General Standards

1 This section deals with Section 4 of the Executive Order.

a Definition of secondary treatment

b Minimum requirements

c Exception to secondary treatment requirement

d Protection of hazardous materials

e Laboratory facilities and maintenance of records

D Review of Federal Water Resources Projects

Joint review by Federal Activities Coordination and Water Resources Projects Branch

E Federal Loans, Grants, and Contracts

Definition

F Vessel Pollution

1 Report to Congress

2 Legislation needed to provide for implementation of the recommendations of the above report

G Reporting

1 Value of information at earliest stage of planning

2 Definition of "large or unusual waste loadings".

H Inter-Agency Memoranda of Understanding

1 Those approved

2 Those pending

V DISCUSSION

This outline was prepared by Herbert C. Clare, P.E., Director Facilities Program, and Herndon S. Hill, P.E., Federal Activities Coordinator, FWPCA, Portland, Oregon.

SECTION III

WASTE TREATMENT METHODS

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Chlorine Determinations and Their Interpretation	17

III-a

WASTEWATER TREATMENT - THE RESULT OF NATURAL PHENOMENA

I INTRODUCTION

All sewage treatment is accomplished by application of biological, physical, chemical processes. These processes are natural phenomena which have been in operation since primeval time. Man has not always understood these processes and in fact we may not have a complete understanding of them at this time; nevertheless, it is by means of these phenomena that sewage treatment is possible.

II PHYSICAL PROCESSES

A Specific Density

The density of waste solids, coupled with the law of gravity, provides a physical phenomena resulting in removal of wastes. Sedimentation has been observed by man for thousands of years and a study of geologic formations reveal that sedimentation has been continuing for millions of years. In nature, the pools in streams, lakes, and estuaries provide the necessary conditions of quiescence to allow gravity separation of settleable solids.

In using the physical laws relating to gravity and specific density, man has used two processes:

1 Sedimentation in tanks built to provide quiescence, and

2 Centrifuge separation

B Particle Size Distribution

Screening sewage flows to remove large particles is merely an application of size selection. Screens abound in nature as settled rock deposits which prevent movement of twigs, sticks, leaves and other solids. The earth itself acts as a fine screen and filter, removing all waterborne material except those that are dissolved. In treatment plants, bar racks and sand filters are applications of these natural conditions.

C Reaeration

Few people have failed to take the time to see a waterfall or to enjoy the scenic beauty of a fast-flowing and turbulent mountain stream. These are nature's examples of reaeration facilities. In addition to these dramatic aerators, there is a constant exchange of molecules of oxygen and other atmospheric gases across the liquid-gas interface of rivers, lakes, ponds, and oceans. The wind provides mixing energy to carry the dissolved gases to portions of the water mass below the surface. Utilizing these principles as treatment processes, man injects air into the waste flow by use of air under pressure; the making of waterfalls by pumping the liquid into the air fountain-like; or, by creating an infinitely large surface area with depth being merely a thin film as the liquid trickles downward over beds of rock.

III BIOLOGICAL PROCESSES

In the real world the aquatic community is very complex, consisting of organisms of every size from the virus to the fishes. Each has a definite role in the community and in a natural environment--one unaffected by wastes from man's activities--there is a very great variety of different kinds and species. All are present in such numbers as will maintain a balance with the food supply available.

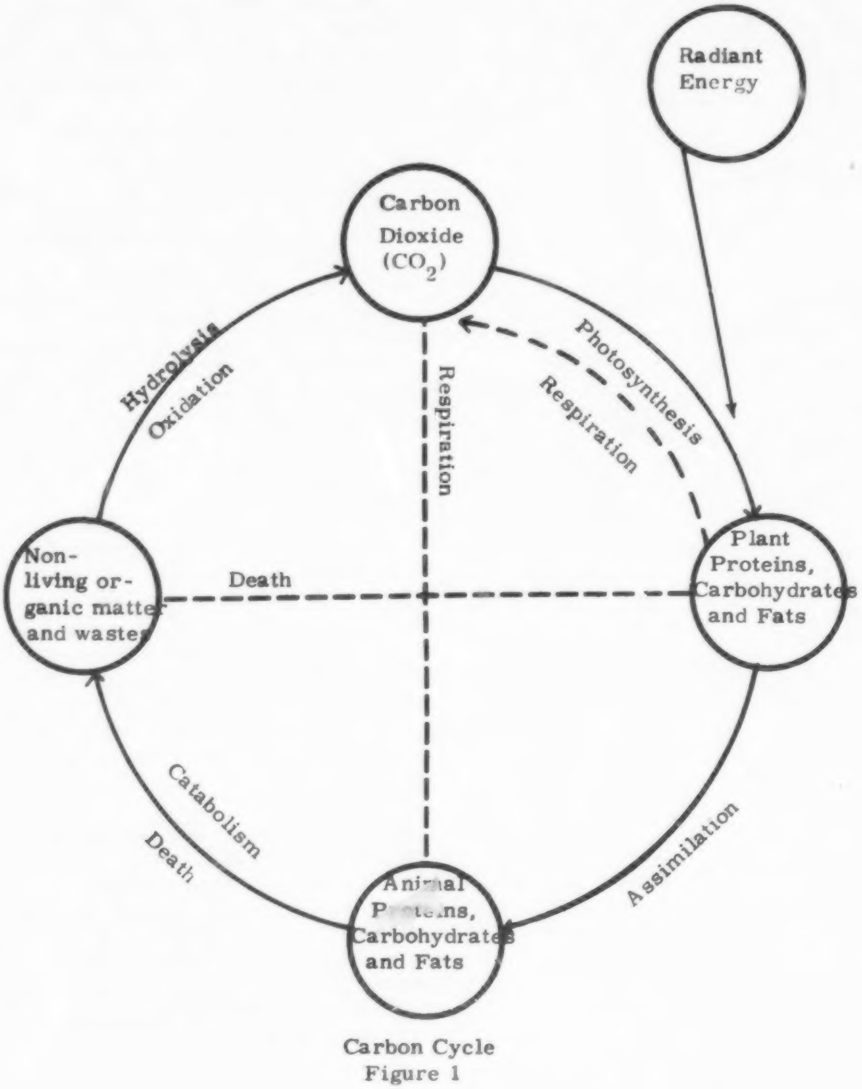
Action by bacteria in this community breaks down complex organic matter to simpler molecular forms. These become the basic building blocks for new growth by other microorganisms. These in turn are a food source for yet other, more complex, organisms. This activity of decomposition and growth is a continuous one--such that the process is cyclic.

All the elemental components of organic material--carbon, nitrogen, sulfur, etc.--are cyclic. The carbon cycle (Figure 1) is an example. It can be seen that once elements making up organic matter, from any source, enter the aquatic environment they will continue in the cycle indefinitely unless they are removed as a "Harvest" as fish or other product.

IV CHEMICAL PROCESSES

Chemical processes in the aquatic environment are intimately connected with biological activity and proceed simultaneously with photosynthesis, assimilation and decomposition.

In addition, the chemistry of water is a function of the solubility and presence of inorganic salts in the environment.


Radiant Energy
Carbon Dioxide (CO_2)
Photosynthesis
Respiration
Respiration
Hydrolysis
Oxidation
Non-living organic matter and wastes
Death
Plant Proteins, Carbohydrates and Fats
Catabolism
Death
Assimilation
Animal Proteins, Carbohydrates and Fats

Carbon Cycle
Figure 1

The salt content of the oceans, the Dead Sea, the Salton Sea, and Great Lake are examples which indicate that once inorganic salts enter the aquatic environment they remain indefinitely as an integral part. It is only by means of evaporation that water high in inorganic salts is returned, in the form of rain and snow, to the fresh water state.

V LIMITATIONS OF NATURAL TREATMENT

A Although wastes discharged into the aquatic environment enter the cycle previously described, time is required to reach a new balance during which time water quality may be seriously impaired. In addition, the new balance may not be a desirable one as excessive nutrients may bring about blooms of organisms causing nuisance conditions and/or foul odors and tastes.

B It is axiomatic that elements of wastes removed prior to discharge into the aquatic environment do not enter these cycles and therefore cannot cause adverse effects.

C A stream has capacity to accept organic wastes and through natural processes to self-purify; however, its capacity to assimilate wastes without seriously affecting water quality for other uses is limited by such factors as stream flow, reaeration rate, temperature, etc.

REFERENCES

1 Fair, G.M. and Geyer, J.C., Water Supply and Waste-Water Disposal, John Wiley & Sons, Inc., New York, (1966).

2 McKinney, R.E., Microbiology for Sanitary Engineers, McGraw-Hill Book Company, New York, (1962).

3 Rich, L.G., Unit Processes of Sanitary Engineering, John Wiley & Sons, New York, (1963).

This outline was prepared by L. J. Nielson, Sanitary Engineer, FWPCA Training Activities, PNWL.

SCREENING - METHODS AND PURPOSES

I GENERAL

Screening of wastewater is conducted as a preliminary treatment step to remove large suspended materials which may be harmful to other plant operations.

II METHODS

In general, screening operations are of two types:

A Screening

Screening and removal of solids for subsequent disposal (usually by burial) is generally achieved by using:

1 Bar screens or bar racks

2 Drum screens

3 Vibrating screens

4 Disc screens

The simplest form of screening, the bar rack, consists of parallel vertical bars inclined to the flow in order to facilitate hand cleaning. This is accomplished by means of a long-handled rake.

In some installations, fixed trash racks are movable and can be raised for cleaning. In this case, dual channels are needed in order to have one rack in service at all times.

Mechanical cleaning is done by moving rakes attached to an endless chain. (Figure 1)

Drum and disc screens are the most widely accepted screens for domestic sewage. Sewage flows through the screen depositing material on the outside. As the screen rotates, material is brushed or jetted off into a screen pit where it is removed by a bucket elevation. (Figures 2 and 3)

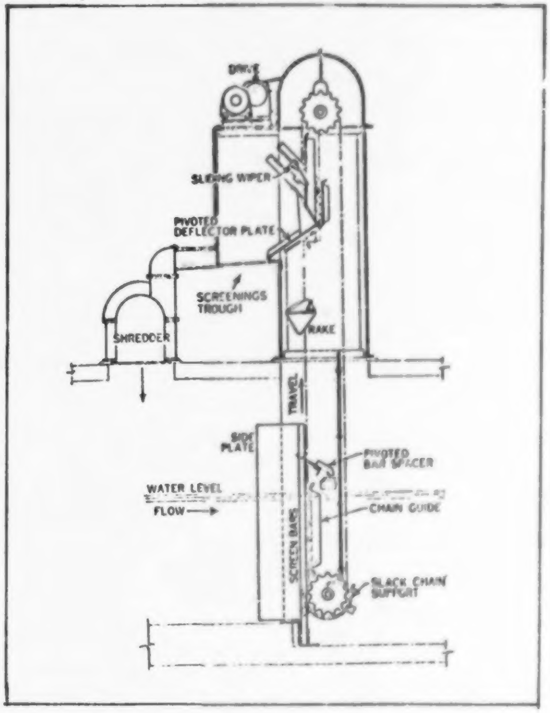


Figure 1: Vertical Section of Bar Screen and Mechanical Rake.

Vibrating screens have received much favorable acceptance in industrial applications for removal of organic solids which would otherwise drastically overload the treatment plant.

Solids removal by use of bar screens is negligible. Fine screens average approximately 10 percent removal of suspended solids and are primarily used to remove fibrous industrial wastes.

B Comminution or Grinding

In cases where grit is not a problem, or following grit removal, incoming material is ground or chopped by means of oscillating cutter bars to reduce large materials to a size that can be handled in the treatment processes.

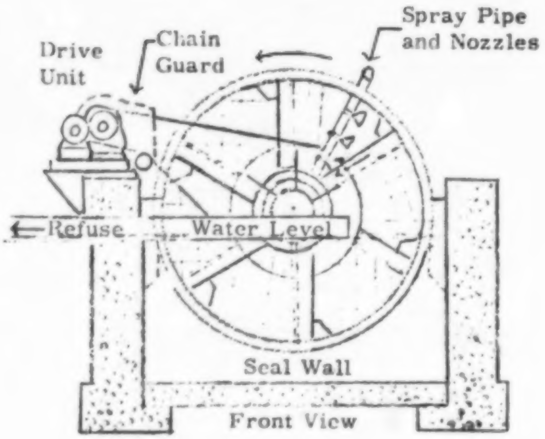

Drive Unit
Chain Guard
Spray Pipe and Nozzles
Refuse
Water Level
Seal Wall
Front View

Figure 2
Disc Screen

There are three major types of equipment in general use for reducing the size of suspended solids:

1 The comminution consists of a rotating, cutting screen. The sewage flow passes through the screen and out the bottom end of the rotating drum. (Figure 4)

2 Barminutors combine the design of the bar screen with a travelling grinder which moves up and down the rack to shred the solids collected on the screen.

3 Grinders and shredders of varied design are available for reducing the size of solids removed from bar screens.

In addition, grinders are frequently used at the waste source to reduce the solids to an acceptable size. The home garbage disposal unit and its commercial and industrial counterpart are examples of such units.

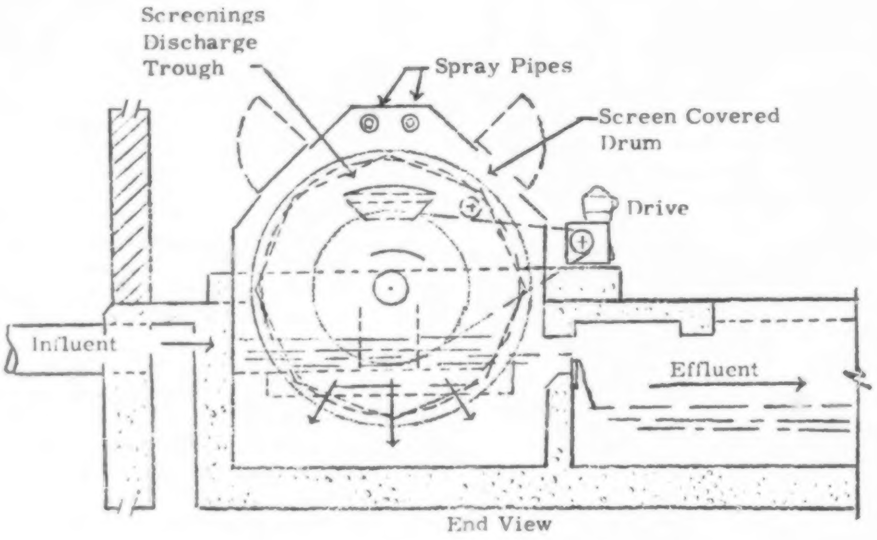

Screenings Discharge Trough
Spray Pipes
Screen Covered Drum
Drive
Influent
Effluent
End View

Figure 3. Drum Screen

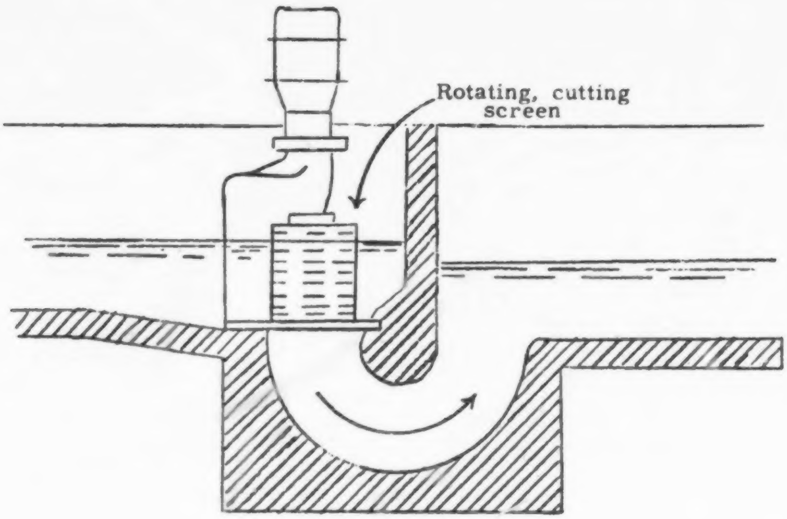


Figure 4. Cutting Screen or Comminuter

III PURPOSES

A Protection

Removal of such solids as large sticks, glass, metal, etc., protects the sewage treatment equipment from damage.

B Reduce Maintenance

Removal or grinding of large suspended solids such as rags, sticks, and certain types of commercial and industrial wastes reduces the potential of clogged pumps and pipe lines with the attendant maintenance problems.

C Increase Plant Efficiency

Reducing the size of organic solids by grinding or communition increases surface area available to bacteria, thus improving digester efficiency.

REFERENCES

1 Fair, G. M. and Geyer, J. C., Elements of Water Supply and Waste Water Disposal, John Wiley & Sons, (1958).

2 Water Pollution Control Federation, Wastewater Treatment Plant Operator Training Course Two, WPCA, Washington, D. C., (1967).

3 Federation of Sewage and Industrial Wastes Associations, Sewage Treatment Plant Design, Washington, D. C, (1959).

4 Water Pollution Control Federation, Operation of Wastewater Treatment Plants, Washington, D. C., (1966).

This outline was prepared by Lyman J. Nielson, Chief, Training, Pacific Northwest Water Laboratory, Corvallis, Oregon.

GRIT REMOVAL - PRINCIPLES AND METHODS

I GENERAL

Grit chambers are used ahead of primary treatment to remove heavy solids which may be harmful to plant operation and equipment.

Grit consists primarily of inorganic materials such as sand, gravel, cinders, glass, and silt and may include organic materials such as coffee grounds, fruit seeds, grain, rags, paper and bits of meat and vegetables. Removal of the inorganic substances in advance of pumps and treatment units prevents wear of machinery and unwanted accumulation of grit in settling tanks and facilitates the handling of sludge produced by various treatment processes.

In separate sanitary systems, grit originates in wash water from kitchens and bathrooms, from washings of floors and from illegal ground or storm water connections and from industrial processes.

In the case of combined sewer systems, in addition to the above, sand and silt enter the systems from street washings through catch basins, from damaged pipe joints and drainage from excavations.

II TYPES OF GRIT REMOVAL FACILITIES

Grit removal facilities can be classified into two types:

A Grit Chambers

Grit chambers are operated at velocities low enough to permit capture of particles of specific gravity 2.65 and 2×10^{-2}cm in diameter.

The design of grit chambers is based on reducing the velocity of incoming sewage to approximately 0.5 to 1.0 f/s for a detention time of one minute. Generally the decrease in velocity is accomplished by an increase in cross sectional area.

Depending on the range in flow, it may be necessary to provide more than one chamber in order to maintain design velocity. Chambers are also designed so that the sewage enters and leaves the chambers with a minimum of turbulence. In smaller plants where mechanical grit removal equipment is not feasible, at least two chambers are required to permit manual removal of accumulated grit. (Figure 1) As manually cleaned chambers do not produce a washed grit, a considerable amount of organic matter is included with the grit. Mechanically cleaned grit chambers are cleaned periodically by some type of collection mechanism and equipment for moving the collected grit to a point of disposal.

B Detritus Tanks

Detritus tanks are operated at a relatively constant level and produce a settled grit containing considerable amounts of organic material which must be removed from the grit before disposal. This material, or detritus, can be removed by one of the following:

1. Re-suspension of the detritus by injection of compressed air.
2. Detritus removal by use of a grit washer.
3. Mechanical scraper for grit removal operated in such a manner as to flush the detritus back into the sewage flow.

III DESIGN CONSIDERATIONS

Grit chamber design requires data on volume and fluccuation of sewage flow and type and quantity of grit.

A Quality

Grit types include sand, gravel, silt, ashes, clinkers, and miscellaneous debris washed from streets. Household discharges, particularly from homes

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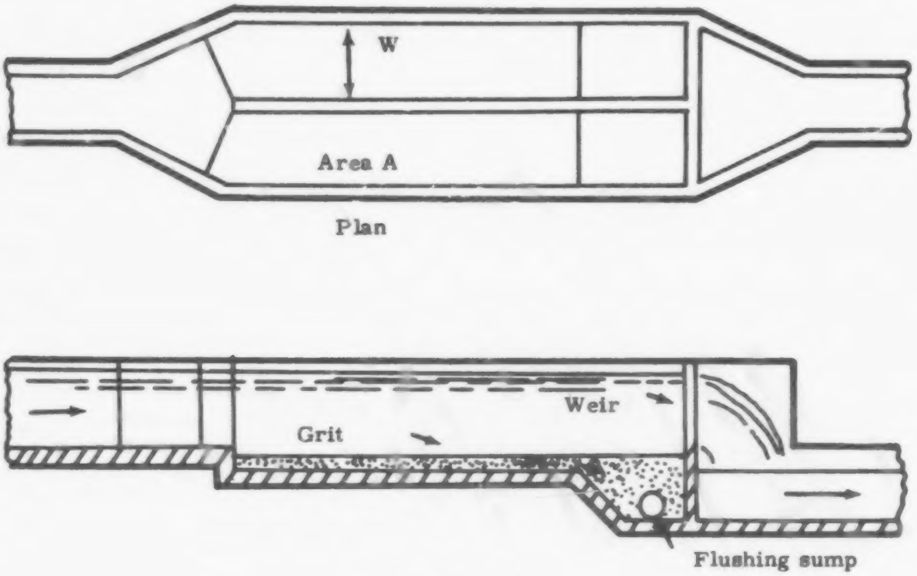

GRIT CHAMBER
Figure 1

equipped with garbage grinders, contribute egg shells, bone chips, coffee grounds, and similar material.

B Quantity

Quantities of grit vary depending upon:

1 Street surface conditions

2 Area served by the sewer system

3 Climatic conditions

4 Types of sewer inlet structures

5 Maintenance of catch basins

6 Amount of storm water diverted from system

7 Sewer grades

8 Condition of sewer system

9 Industrial wastes

10 Use of household grinders

C Design Theory

1 A principal feature of grit chamber design is the use of differential sedimentation. Successful grit chamber operation is possible because of the difference in settling rates between inorganic grit particles and organic slides.

2 Settling characteristics of the grit particles to be removed provides the basis for chamber design. The design loading is normally expressed in surface overflow rate with depth qualified, or as linear flow velocity with length as a qualifier.

Table 1 THEORETICAL MAXIMUM OVERFLOW RATES FOR GRIT CHAMBERS

Size of Grit Particles, Diameter, mm	Average Settling Velocity of Quartz Particles (specific gravity 2.65) in Water, Fpm	Theoretical Maximum Permissible Overflow Rate for Substantially Complete Removal (Gpd per Sq Ft)		
		Specific Gravity 2.65	Specific Gravity 2.0	Specific Gravity 1.5
0.83	16.2	174,500	105,800	52,900
0.59	11.9	128,000	77,600	38,800
0.42	8.1	87,000	52,800	26,400
0.30	6.1	65,500	39,600	19,800
0.25	5.4	58,000	35,200	17,600
0.21	4.3	46,300	28,000	14,000
0.18	3.8	40,900	24,800	12,400
0.15	3.0	32,300	19,600	9,800

(Sewage Treatment Plant Design -- FSIWA Manual of Practice No. 8)

From Table 1 it can be seen that a grit chamber designed to remove 100% of minimum sized grit would also remove all larger grit particles.

The theoretical detention time is that required for the minimum size particle to reach the bottom of the tank for removal.

Other factors affecting removal of grit are:

a Turbulence of flow in the chamber which may hinder settling.

b Bottom scour is an important factor in grit chamber efficiency. Re-suspension and/or movement of settled grit, because of the flow velocity above a certain critical velocity, may be the controlling factor in determining flow velocity in the chamber.

3 Velocity control

Because of variations in flow, it is necessary to design the structure to maintain the design velocity.

a Proportional weir

b Sutro weir

c Rectangular control section

d Parshall flume

e Mechanical velocity control devices

4 Other design considerations

a Accessibility of chamber and appurtenances for cleaning and maintenance

b Grit storage in chamber

c Method of grit removal

d Arrangement of units

REFERENCES

1 Fair, G.M. and Geyer, J.C. Elements of Water Supply and Wastewater Disposal, John Wiley & Sons, (1958).

2 Water Pollution Control Federation, Wastewater Treatment Plant Operator Training Course Two, WPCA, Washington, D.C., (1967).

3 Federation of Sewage and Industrial Wastes Associations, Sewage Treatment Plant Design, Washington, D.C., (1959).

4 Water Pollution Control Federation, Operation of Wastewater Treatment Plants, Washington, D.C., (1966).

This outline was prepared by L. J. Nielson, Sanitary Engineer, FWQA Training Activities, PNWL.

SEDIMENTATION BASINS IN WASTEWATER TREATMENT

I FUNCTION AND TYPE OF SEDIMENTATION BASIN

A Function

1 Grit removal

2 Primary sedimentation

a Alone or in advance of other processes

b With or without chemicals

3 Secondary sedimentation - following biological treatment

4 Sludge thickening

B Shape and Type

1 Horizontal flow - mechanical sludge removal

a Rectangular

b Circular

1) Center feed

2) Peripheral feed

c Imhoff tank

d Septic tank

2 Vertical flow

3 Tube settler[10]

II TYPICAL DESIGN CRITERIA

A Overflow Rates

Most State Standards specify maximum overflow rates in primary tanks of from 600 to 1,000 gpd per square feet with smaller plants using the lower rates. In secondary clarifiers, maximum overflow rates of 800-1,000 gpd per square feet are commonly specified.

B Detention Time

Some states set limits on both maximum overflow rate and minimum detention time. A figure of 2 hours' detention for primary tanks is common although shorter times are permitted for primary tanks ahead of activated sludge. For secondary tanks, 2 hours' detention is a common specification. The Ten State Standards do not specify detention times, but do set a minimum depth of 7 feet on primary and 8 feet on secondary tanks, which is tantamount for setting a minimum detention time, since

$$T = \frac{180\ D}{V_o}$$

where T = Detention time (hours)
D = Tank depth (ft)
V_o = Overflow rate (gpd per sq. ft.)

Thus, a tank with an overflow rate of 600 gpd per sq. ft. and a depth of 7 ft. has a detention time of 2.1 hours.

C Weir Loading

A number of states specify weir loading rates of the order of 10,000-15,000 gpd per lin. ft.. of effluent weir.

D Other Criteria

Some states specify minimum distances from inlet to outlet, scum baffles are commonly required, and, as a rule, some requirement is set regarding even distribution of flow and dissipation of kinetic energy at the inlet.

III THEORY OF SEDIMENTATION

A Allen Hazen[1]

Hazen's paper published in the Transactions of the American Society of Civil Engineers in 1904 outlined the commonly accepted theory of settling of discrete particles in quiescent basins and discussed the effect of departures from ideal conditions. According to this theory sedimentation efficiency is a function of overflow rate and independent of depth.

B Thomas R. Camp[2]

Camp's paper on the Transactions of the American Society of Civil Engineers in 1946 elaborated on Hazen's theory, outlined the use of settling tube tests to determine the properties of suspensions, discussed settling of flocculent suspensions, scour of deposited materials, the effects of short circuiting and turbulence. He recommends the use of long shallow tanks for sedimentation with the depth being limited only by considerations of avoiding scouring velocities and the need for sludge removal equipment. This paper with the discussions that accompany it is probably the best single paper on the subject of sedimentation basin design.

Quote from the discussion of the paper.

E. Sherman Chase: ". . . . the design of practicable settling tanks will continue to be based upon judgment, experience, and common sense seasoned with a moderate amount of theoretical computations used as aids to judgment."

T. R. Camp: "This attitude has undoubtedly been that of most of the designers of tanks . . . . The moderate amount of theoretical computations which Mr. Chase suggests for seasoning the judgment has unfortunately been so moderate that it has been almost completely absent. Design has consisted almost wholly of conformity to previous practice in size and shape with little regard for the principles involved or for the nature and settling characteristics of the particles to be settled."

C E. B. Fitch[3]

Fitch, in Sewage and Industrial Wastes in 1957, makes the point that in dealing with flocculent suspensions a deep tank provides better opportunity for particle growth than a shallow one and hence that detention time cannot be discarded as a criterion in settling tank design. He also points out that hydraulic efficiency or absence of short circuiting is not necessarily important to good tank performance.

D Ronald T. McLaughlin[4]

McLaughlin, in the Hydraulics Division Journal of ASCE in December, 1959, points out how the properties of the suspension determine whether detention time, overflow rate, or both may be important to efficient sedimentation.

IV COMPLICATING FACTORS

A Flocculation

Most of the suspensions dealt with in wastewater treatment do flocculate. Exception - Grit. Extreme case - Activated sludge. Intermediate - Raw sewage.

B Flow Variations

The typical wastewater treatment plant is subject to wide variations in flow. It is virtually impossible to design a sedimentation tank that will behave in the same way hydraulically with flow varying by as much as a factor of 5-10 from maximum to minimum.

C Solids Removal

Sludge and scum removal mechanisms perturb somewhat the settling of suspended matter. It is necessary to consider a portion of the tank volume ineffective because of the operation of these mechanisms.

D Solids Concentration

It is commonly found that removal efficiency of sedimentation basins is higher when dealing with concentrated suspensions than when influent concentrations of suspended solids are low. It is not usually known why this is so. In some cases, it may be due to differences in the size distribution of the suspension. Many sewers act as crude settling basins which are periodically flushed out. At times of flush-out, this relatively coarse material reaches the treatment plant. High concentrations of suspended solids make for more effective flocculation as well. This accelerates settling.

E Inlet Design

A portion of any tank is ineffective for sedimentation because of need to dissipate influent kinetic energy and distribute flow evenly. In long tanks, the ineffective fraction of the tank is smaller than in short tanks. Flow variations and the necessity of avoiding small openings usually prevent the introduction of a controlling head loss to get even flow distribution.

F Density Currents

Virtually all tanks are affected by density currents. Activated sludge secondary tanks always have them, and most primary tanks have them from time to time. Anderson[5] has developed a design of secondary tank with an annular weir to improve efficiency of circular tanks. Gould in New York adopted another way of coping with density currents in rectangular secondary tanks. He places the sludge hopper near the effluent end of the tank instead of at the influent end.

G Resuspension of Deposited Solids

This limits acceptable horizontal velocities. Camp, using Shields formula, estimates that velocities as high as 7-8 fpm are acceptable. In primary tanks at Hyperion, there was evidence of resuspension when velocities exceeded about 4 fpm.[6] The presence of density currents can affect resuspension markedly. Burgess and his colleagues[7] studied flow patterns in the primary tanks of the Northern Outfall Works of the London County Council and found a very marked density current.

V PLANT PERFORMANCE

Comparatively few extensive studies of plant performance to guide engineer in design.

A NRC Study of Military Treatment Plants[8]

Studied 20 months of operating data from 18 primary plants. Mean BOD removal for the 18 plants ranged from 10 per cent to 61 per cent. Not only was there large variation between plants but also large variation in a given plant from one period to the next. Average detention period for the 18 plants was 3.77 hours, average overflow rate was 506 gpd per sq. ft. Median displacement velocity was 0.4 fpm. Detention period correlated more closely with removal efficiency than did overflow rate. There was no significant difference between circular and rectangular tanks, other things being equal. The following formula was used to fit the data for 10 plants where there was no recirculation to the primary tanks:

$$\text{Fractional Removal of Suspended Solids} = \frac{0.67\ T}{1 + 0.94\ T}$$

B Data in ASCE - WPCF Manual of Sewage Treatment Plant Design[9]

An analysis of data from 32 plants [illegible] rectangular primary tanks and 25 plants with circular primary tanks has been made. The following table shows data on size, loading, and performance at these plants:

	Rectangular Tanks		Circular Tanks	
	Mean	Std. Dev	Mean	Std. Dev
Length or diameter ft.	118	53	86	32
Depth, ft.	10.3	1.85	10.5	1.98
Length/width	3.77	1.49	-	-
Detention time, hrs.	[illegible]	1.44	2.65	1.12
Overflow rate, gpd/ft^2	957	535	856	360
Influent suspended solids, mg/l	227	105	234	71
Effluent suspended solids, mg/l	106	60	[illegible]	33
% removal suspended solids	52.6	15.5	60.8	11

Multiple correlation analysis were made on these data, using per cent removal of suspended solids as the dependent variable and various parameters as independent variables. There was little to choose between detention time and overflow rate as variables in predicting performance. There was no indication of marked superiority of one shape of tank over the other. As in the NRC study, there is a wide scatter of points about the fitted curve.

Equations fitted to the data were

Circular Tanks

$$\text{Fraction S. S. removed} = \frac{2.5\ T}{1 + 3.8\ T} \quad \text{and}$$

$$\text{Fraction S. S. removed} = \frac{2,940}{4,100 + V_o}$$

Rectangular Tanks

$$\text{Fraction S. S. removed} = \frac{.49\ T}{1 + .55\ T} \quad \text{and}$$

$$\text{Fraction S. S. removed} = \frac{1,350}{1,920 + V_o}$$

where T is detention time in hours

V_o is overflow rate in gallons per day per square foot.

C Secondary Clarifiers at Chicago Activated Sludge Plants

A secondary clarifier in an activated sludge plant is called upon to do a vastly more efficient job of solids separation than one expects of primary tanks. The influent contains thousands of mg/l of suspended solids and the effluent is expected to contain only tens of mg/l of suspended solids. Thus, we look for 99 percent or more removal of suspended solids. To achieve this, it is essential that the activated sludge be well flocculated and that only a small amount of the suspended solids be in small particles.

An analysis of two years operating data from five of the operating batteries at the three large Chicago activated sludge plants has been made to get some insight into the importance of various operating variables in determining plant performance.

The analysis showed clearly the superiority of the Anderson design with annular weirs over the older design with peripheral weirs. Overflow rate was not an important determinant of effluent suspended solids, although the five batteries had an average overflow rate of over 1,200 gpd per sq. ft. Temperature had a significant effect on clarifier efficiency. An organic loading parameter, pounds of BOD per day per pound of mixed liquor suspended solids, had a greater effect than either of the other variables.

The plants had average loadings of .19 pounds of BOD per day per pound of mixed liquor suspended solids with a range of monthly values of this parameter from .09 to .51. Effluent suspended solids for all of the plant units were 15 mg/l, with monthly averages ranging from 5 to 96 mg/l.

Sludge volume index was not a significant index of performance. It should be pointed out, however, that sludge volume indices were quite low, averaging 75 and varying from 46 to 139.

This analysis indicates that with well flocculated activated sludges excellent solids separation can usually be obtained at overflow rates considerably higher than those usually recommended. However, from time to time one must expect the system to get out of control and suspended solids carry-over in the effluent to occur.

VI CONCLUSION

In spite of the fact that theoretical considerations indicate that overflow rate should be a more significant parameter than detention time in design of sedimentation basins, plant performance data do not support the superiority of one design parameter over the other in plants with conventional depths.

Sedimentation basins generally show rather erratic performance in time. This is probably due at least in part to the inherent instability of flow patterns in basins with horizontal velocities low enough to prevent resuspension of deposited material. Flow fluctuations, changes in waste composition, wind, and solar radiation are other perturbing influences.

Although circular horizontal flow tanks are notoriously prone to short circuiting their performance in solids removal appears to be as good as that of rectangular tanks similarly loaded. The lower maintenance costs of sludge removal mechanisms in circular tanks is probably the most important factor in choosing between circular and rectangular tanks.

There is no rational basis for the relatively low overflow rates set by most of the state design standards. At small plants where the marginal cost of providing additional tank capacity is proportionately much less than in larger plants, there is probably not much reason to skimp on basin size, but in larger plants there may be significant economy in using higher rates. Overflow rates much higher than the conventional 600-1,000 gpd per sq. ft. are used in many plants with good efficiency.

There is little reason for maintaining low weir loading rates in primary tanks. In secondary tanks following activated sludge low weir loadings are important.

The tube settlers[10] that have been introduced recently have not as yet been tested enough for any conclusion to be reached as to their general usefulness in wastewater treatment. This development will be watched with interest.

REFERENCES

1 Hazen, Allen. On Sedimentation. Trans. ASCE, 53. 45-88. 1904.

2 Camp, Thomas R. Sedimentation and the Design of Settling Tanks. Trans. ASCE III. 895-957. 1946.

3 Fitch, E. B. The Significance of Detention in Sedimentation. Sewage and Industrial Wastes 29. 1123-1133. 1957.

4 McLaughlin, Ronald T., Jr. The Settling Properties of Suspensions. Proc. ASCE. Jour. Hydraulics Div. 85. No. HY-12. 9-41. 1959.

5 Anderson, Norval E. Design of Final Settling Tanks for Activated Sludge. Sewage Works Journal 97. 50-65. 1945.

6 Theroux, Robert J. and Betz, Jack M. Sedimentation and Preaeration Experiments at Los Angeles Sewage and Industrial Wastes 31. 1259-1266. 1959.

7 Burgess, S. G., Green, A. F., and Easterby, Patricia A. More Detailed Examination of Flow in Sewage Tanks, Using Radioactive Tracers. Jour. and Proc. Inst. of Sewage Purification, Part 2. 184-192. 1960.

8 Subcommittee on Sewage Treatment. National Research Council. Sewage Treatment at Military Installations. Sewage Works Journal 18. 789-1028. 1946.

9 Sewage Treatment Plant Design. WPCF Manual of Practice No. 8. 90-91. 1959.

10 Hansen, Sigurd P., Culp, Gordon L., and Stukenberg, John R. Practical Application of Idealized Sedimentation Theory Paper, Presented at WPCF Conference, New York City. October 10, 1967.

This outline was prepared by R. L. Woodward, Camp, Dresser and McKee Engineers, Boston, Massachusetts.

SEDIMENTATION TANK EQUIPMENT

I INTRODUCTION

The primary objectives of sedimentation equipment is the removal of settleable solids and floatable scum.

A Primary sedimentation objectives are to remove concentrated sludge without troublesome septicity.

B Secondary sedimentation requires prompt return of fresh solids with concentration as a secondary requirement.

C Basin, sludge collection, scum removal, drive mechanisms and available equipment will be discussed relative to A and B.

II SLUDGE COLLECTION EQUIPMENT

A General

Much equipment available, more similarities than differences. Three basic shapes of tanks: circular, rectangular, square.

B Circular Clarifier - Center Inlet

1 General

Most common flow pattern. Sewage enters center well, either through side of tank, or underneath and up. Sewage flows downward, then radially, over a peripheral weir.

2 Manufacturers

Infilco, Carter, Eimco, Yeomans, Dorr, Rex, Walker, Link-Belt, Hardinge.

3 Beam Supported Type

Scraper blades mounted on truss revolve about center shaft scraping sludge to central well. Supported from beams spanning tank. Full weight and torque carried by beams. For small tanks, usually 50 ft. in diameter or less. Motor driven at center. Skimmer connected to same shaft.

4 Center Column Type

For larger tanks up to 200 ft. diameter. Scraping mechanism similar to beam supported type. Scraper assembly suspended from a turntable carried by a central column. Rotated by means of motor driven gears mounted on a fixed bridge. Sewage enters up through hollow column, then flows radially.

5 Peripheral Drive

Center column. Rotating bridge drives scraping assembly. Driven peripherally by motor driven wheels on wall of tank. Not too common in New England. Snow and ice problems. Manufacturers: Infilco, Eimco, Walker.

6 Suction Type

For secondary sludge, mainly activated sludge. Suction pipes mounted on scraper truss. Suction created by hydrostatic head. Eimco, Dorr, Rex, Walker.

7 Radial Chain Scraper Type

Not common. Radially mounted endless chain type, scraping towards center while rotating. Peripheral drive. Link-Belt.

C Circular Clarifier - Peripheral Inlet

Sewage enters tangentially into a peripheral race. Skirt extends to 18" from floor. Sewage flows under skirt, then upward and over central weir. Scum, in theory, remains in raceway. Sludge removal equipment bridge supported. Lakeside, Yeomans, Rex.

D Rectangular Tanks

1 General

Sewage enters at end, is baffled, flows longitudinally to other end, out over weir.

2 Standard Chain Type

Oldest type. Chain and sprocket type. Flights attached to chains run on rails. Scrape sludge to hopper at inlet end. Cross collectors provided in hoppers of large tanks. Rex, Walker, Link-Belt, Yeomans, Jeffrey.

3 Moveable Bridge Type

Bridge spans tank width, running on rails. Rakes hung from bridge contact floor and move sludge to end of tank.

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a Traction drive

Motor mounted on bridge. Electricity supplied by reel and cable. Hardinge, Link-Belt, Rex, Komline-Sanderson.

b Cable drive

Stationary drive at end of tank. Pulls cables attached to moving bridge. Dorr.

E Square Tanks

Flow can be center inlet, peripheral weir; or straight across flow. Mechanism similar to circular tanks except for extension arms which reach into corners, and scrape sludge back to normal radius of scraper. Not common. Dorr, Walker, Link-Belt, Rex.

III SCUM REMOVAL MECHANISMS

A Circular Tanks (Primary)

Skimming device rotates on center shaft. Details vary, but all types force scum towards periphery where it is deposited in scum box. Flows or is flushed to scum pit. Peripheral feed: Scum in raceway flows to a tilting skimming pipe. Incomplete removal. Scum still rises in main settling tank.

B Rectangular Tanks (Primary)

Return flights travel the surface forcing scum to end. Usually picked up in a revolving skimming pipe. Other types.

C Secondary Tanks

It is not standard practice to install scum removal mechanisms on secondary tanks. However, observations in Northeast Region leads us to believe that they are needed. We have been thinking of making this a firm requirement.

IV DRIVE MECHANISMS

Slow speed of rotation requires a large speed reduction ratio. Various types of reducers and gearing arrangements used, depending upon diameter (or length) of tank and sludge load.

This outline was prepared by S. C. Peterson, Chief, Construction Grants Activities, Northeast Region, FWQA, Boston, Massachusetts.

DETERMINING EFFICIENCY OF SETTLING TANKS AND CLARIFIERS

I INTRODUCTION

A The need for examination of sewage as it enters and leaves sedimentation tanks varies from plant to plant. In deciding which tests are essential, the operator must take into account the treatment units which follow, such as trickling filters, aeration tanks, intermittent sand filters, and sludge digestion and dewatering facilities.

B Where the effluent is discharged to receiving waters without further treatment, the operator must select tests which will measure the impact on the stream.

II TESTS FOR DETERMINING EFFICIENCY

A Suspended and Settleable Solids

1 Tests for settleable and suspended solids are used to measure the effectiveness of sedimentation. These tests should be made daily on composited samples at large plants and at least twice weekly at smaller plants where laboratory work is conducted.

2 Samples should be taken of the influent and effluent of the tank at parts where the sewage is well mixed.

3 Test results indicate the clarity of the effluent and the loading of suspended matter on the receiving waters or the biological treatment units which may follow. They also indicate the quantity of sludge to be treated and disposed of.

4 Efficiency of solids removal by sedimentation can be calculated from influent and effluent data.

B Biochemical Oxygen Demand

1 The five-day biochemical oxygen demand test provides a good measurement of sewage strength.

2 Tests on composite samples of influent and effluent should be made daily and never less frequently than twice weekly, even in small plants.

3 Tests on the tank effluent provide a good measure of the strength and quantity of the organic loading imposed on subsequent biological processes or on the receiving waters.

III TEST PROCEDURES

A Settleable Solids Test

1 Sampling - Catch samples at period of maximum flow and if possible allow for the lag in time equal to the flow-through period of the settling tank.

2 Equipment - Two Imhoff cones, one for influent and one for effluent. These are large glass cones of one-liter capacity, the lower ends of which are graduated in milliliters (ml). They should be cleaned with strong soap and hot water, using a brush. Wetting of the cone with water before use helps to prevent adherence of the solids to the sides. A wooden rack or shelf should be provided to hold the cones.

3 Procedure

a A measured quantity of well-mixed sample, usually one liter, is gently poured into the cone and allowed to stand for a total period of one hour.

b After the sample has stood forty-five minutes, gently rotate the cone between the hands so as to loosen the solids that adhere to the sides.

c Allow to settle fifteen minutes longer.

d Read from the graduations the volume of solid material deposited in the cone making allowances for any unfilled portions of the cone below the level of the settled solids.

4 Results are expressed as ml of solids per liter which settled in one hour.

$$\text{ml of solids} \times \frac{1000}{\text{ml of sample}} =$$

ml of settleable solids per liter

If the samples represent the influent and effluent of a tank, the efficiency of the tank may be found.

$$\frac{\text{ml of solids per liter of influent} \; (-) \; \text{ml of solids per liter of effluent}}{\text{ml of solids per liter of influent}} \times 100 =$$

percent of settleable solids removed

B Suspended Solids Test

1 Sampling - The same samples that were collected for the settleable solids test should be used for this test, or preferably, an integrated sample adequately refrigerated.

2 Equipment - Gooch crucibles, a filter flask with fittings, aspirator filter pump, drying oven, desiccator, analytical balance with weights, graduated cylinder (100 ml), washed and ignited medium asbestos fibre, and a gas burner with tripod and triangles or an electric muffle furnace.

3 Procedure

a Prepare a suspension of 15 grams of medium asbestos fibre in 1000 ml of distilled water and pour a portion through the Gooch crucible in the filter flask to make a mat about one-eighth inch thick.

b Carefully remove the mat with a spatula or tweezers. Invert and replace in the Gooch crucible.

c Wash with 100 ml distilled water.

d Dry crucible with mat in oven at 103° C.

e Ignite crucible and mat in muffle furnace or over gas burner.

f Cool in desiccator and weigh.

g Again place crucible in filter flask and pour a measured amount of the well-mixed sample into the crucible and filter it through. Filtration is faster if sample is added in small increments. For settled sewage or plant effluents, larger portions should be used.

h Rinse the graduated cylinder with distilled water and pour through the filter.

i Dry the crucible in the oven for one hour at 103° C.

j Cool in desiccator and weigh.

4 Results are expressed as parts per million (ppm). The difference between the weight of the crucible before filtering and the weight of the crucible after filtering is the weight in grams of the total suspended solids.

$$\text{weight of suspended solids in grams} \times \frac{1,000,000}{\text{ml of sample}} =$$

ppm total suspended solids

5 If the samples represent the influent and effluent of a tank, the efficiency of removal of suspended material can be calculated.

$$\frac{\text{mg of suspended solids per liter of influent} \; (-) \; \text{mg of suspended solids per liter of effluent}}{\text{mg of suspended solids per liter of influent}}$$

$\times 100$ = percent of suspended solids removed

C BOD

1 Sampling - The samples which represent the influent and effluent will require dilution depending upon the sewage strength.

2 Equipment and procedures for conducting the test are considered in subsequent outlines.

3 Efficiency of BOD removal in the settling tanks can be calculated from the influent and effluent data.

REFERENCES

Manual of Instruction for Treatment Plant Operators, Distributed by Health Education Service, P.O. Box 7285, Albany, New York 12224.

Operation of Wastewater Treatment Plants, WPCF Manual of Practice #11, Water Pollution Control Federation, Washington, D.C., (1966).

This outline was prepared by D. S. May, Microbiologist, FWQA Training Activities, PNWL.

ANAEROBIC PROCESS PRINCIPLES

I INTRODUCTION

A Definition

1 Anaerobic digestion is the biological conversion of organic matter in the absence of molecular oxygen to simple compounds. The end products of this conversion are chiefly methane and carbon dioxide. Since molecular oxygen is absent, the removal of methane and other reduced gases represents the BOD removal from waste under anaerobic digestion.

B Type of Anaerobic Processes

1 "Conventional" process generally used for treatment of concentrated wastes such as primary and secondary sludges such as at municipal sewage treatment plants.

2 "Anaerobic contact process" designed to handle more dilute wastes and generally applied to specific industrial wastes.

C Process Units

1 Septic tanks

2 Imhoff tank

3 Conventional digesters

   a Standard

   b High-rate(1)

4 Anaerobic contact

5 Anaerobic lagoons

D Micro-organisms

1 The micro-organisms responsible for anaerobic digestion are naturally found in soil, mud and water. Domestic and animal wastes contain large populations of these organisms.(2)(3)

2 Anaerobic treatment is a two-stage process

   a Acid-forming bacteria

   b Methane forming bacteria

II MICROBIOLOGY AND BIO-CHEMISTRY

A General

1 The anaerobic digestion process is well suited to the treatment of suspended solids as well as soluble wastes. In general, any waste susceptible to aerobic treatment can be treated anaerobically. In some cases, such as with cellulose, anaerobic treatment is more satisfactory than aerobic.

2 As a result of the limited oxidations imposed under anaerobic conditions, the energy obtained from a given unit of substrate is much less than it would generally be under aerobic conditions.

3 The anaerobic digestion process as a whole is brought about by the cooperative efforts of a large number of micro-organisms. These micro-organisms may be divided into two functional groups - the "acid formers" and the "methane bacteria."

B Acid Formation

1 The "acid formers" which transform the waste into short chain fatty acids as their major end product are generally anaerobic or facultatively anaerobic. This group encompasses a large number of bacteria with a wide range of talents. As a rule, the acid formers

are less sensitive to environmental factors than are the methane formers. Many of the acid formers are quite versatile as to substrate and end product while others are quite limited. Hence, in some cases, components of the waste may be taken to short fatty acids by a single organism, while in other cases, this transformation may require several organisms.

2 As pointed out by McCarty(4) acetic and propionic acids are the major intermediates of these transformations. This is not to infer that higher fatty acids are not found in a well functioning digester, but that these higher acid end products are further broken down to acetic and propionic acids and hence are only found in small concentrations under normal conditions. About 15 per cent(4) of the methane formed during the digestion of the complex waste results from this intermediate transformation of higher fatty acids and other intermediates to propionic and acetic acids. The group of organisms responsible for these latter transformations although they frequently produce methane, are nevertheless acid formers as this is their major end product.

C Methane Fermentation - Acid Utilization (Table 2)

1 Methane fermentation is carried out by a group of organisms generally termed the methane bacteria. These bacteria are strictly anaerobes and hence quite sensitive to even trace amounts of molecular oxygen - this has resulted in extreme difficulty in isolating pure cultures and hence is basically responsible for the limited work on these organisms. The methane bacteria are also sensitive to other environmental factors such as pH, temperature, and various ion concentrations. The sensitivity of this group and possibly its slow growth rate is usually the limiting factor in the anaerobic digestion process.

2 The methane bacteria as a group are capable of transforming the end products of the acid formers to methane and carbon dioxide as the major end products. The ability of individual methane bacteria to ferment various substrates is quite limited and as a result, many species are required to bring about the desired transformations. Acetic acid is the most common substrate in the anaerobic digestion process.

3 The major mechanisms by which methane is formed is by acetic acid clevage whereby the methyl carbon becomes methane and the carboxyl carbon becomes carbon dioxide. The second major mechanism is the reduction of carbon dioxide to methane.

D Yeasts and Molds

Fungi, including species of yeasts and molds are present in the process of digestion of sludges in sewage treatment systems. Whether they are an important factor in digestion has not been determined.(5)

III ENVIRONMENTAL FACTORS

A Biological - Nutrients(6)

1 Nitrogen and phosphorous - usually present in sufficient amounts in domestic wastes - may be required in some industrial wastes. Nitrogen must be added in NH_3 form, as NO_2, NO_3 forms are reduced and N_2 is evolved, hence lost.

2 Trace elements - Fe(7), Mn, Mg, K, Ca, S, etc. - seldom a problem as waste usually contains sufficient amounts.

B Physical

1 Hydraulic loading

2 Temperature

a Mesophilic 85° to 100°F.

b Thermophilic 120° to 135°F

3 Mixing

C Chemical

1 pH - range from about 6.6 to 7.6

2 Toxic materials

a Certain alkali and alkaline-earth are stimulatory at low levels and inhibitory at higher levels as shown in Table 1.(8)

b Ammonia toxicity

c Sulfide toxicity(9)

d Heavy metal toxicity(4, 10)

e Toxic organic materials

D Acclimation

1 Tolerance to certain cations can be increased by acclimation.(8)

IV OPERATION

A Control

1 Control of the pH of the anaerobic process depends on the maintenance of an adequate bicarbonate buffer system. A proper buffer system counteracts the acidity of the carbon dioxide as well as the acidity of the organic acids produced.

2 Use of ORP(3, 11)

3 Buswell(12) lists factors that interfere with digestion as:

a Sudden increase in feed

b Sudden change in pH of raw waste

c Sudden slug of inorganic material such as Zn, Cu, CN or "salts".

d Sudden temperature change

B Digester Seeding

1 Value of adding digested sludge to start digesters probably lies in production of favorable environmental conditions and not in the numbers of bacteria added.(13)

C Aids to Digestion

Distressed digestion can be attributed to a number of factors, all of which directly or indirectly alter the micro-biological environment. In certain cases, a more favorable environment to these organisms can be provided by restoring the favorable environment by providing buffing alkalinity. Lime has been used and reported in many cases. Agricultural ammonia has been found to be successful in certain applications.(14)

V SUMMARY

A Anaerobic digestion processes are capable of treating high amounts of organic matter in less space than aerobic.

B Sludge accumulation is less due to energy obtained by micro-organisms during metabolism under anaerobic conditions.

C Environmental control major factor in effective operation.

D Methane produced represents a useful fuel and represents major BOD removal.

Table 1. STIMULATORY AND INHIBITORY CONCENTRATIONS OF ALKALI AND ALKALINE-EARTH CATIONS(4)

	Concentrations in mg/l		
Cation	Stimulatory	Moderately inhibitory	Strongly inhibitory
Sodium	100-200	3500-5500	8,000
Potassium	200-400	2500-4500	12,000
Calcium	100-200	2500-4500	8,000
Magnesium	75-150	1000-1500	3,000

Table 2. METHODS OF PREDICTING METHANE PRODUCTION(11)

Empirical Equation:

$$C_nH_aO_b + (n - a/4 - b/2)\,H_2O$$

$$(n/2 - a/8 + b/4)\,CO_2 + (n/2 + a/8 - b/4)\,CH_4$$

1 Reactions not involving reduction of carbon dioxide

$$CH_3COOH \rightarrow CO_2 + CH_4$$

$$4CH_3OH \rightarrow 3CH_4 + CO_2 + 2H_2O$$

2 Reduction of carbon dioxide without net decrease

$$4HCOOH \rightarrow CH_4 + 3CO_2 + 2H_2O$$

$$4CH_3CH_2COOH + 2H_2O \rightarrow 7CH_4 + 5CO_2$$

3 Reduction and net decrease of carbon dioxide

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

$$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3COOH$$

$$2CH_3(CH_2)_2CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3(CH_2)_2COOH$$

$$4CH_3CHOHCH_3 + CO_2 \rightarrow CH_4 + 4CH_3{-}CO{-}CH_3 + 2H_2O$$

$$2CH_3(CH_2)_2COOH + CO_2 + 2H_2O \rightarrow CH_4 + 4CH_3COOH$$

REFERENCES

1 Pohland, F.G. and Engstrom, R.J. High-Rate Digestion Control. Proceedings 19th Industrial Waste Conference, Purdue University. 1964.

2 Imhoff, Karl and Fair, G.M. Sewage Treatment. John Wiley and Sons, Inc., New York. 1956.

3 Burbank, N.C., Cookson, J.T., Goeppner, J. and Brooman, D. Isolation and Identification of Anaerobic and Facultative Bacteria Present in the Digestion Process. Proceedings of the 19th Industrial Waste Conference, Purdue University. 1964.

4 McCarty, Perry L. Anaerobic Waste Treatment Fundamentals. Public Works, 9: 107-112, 10: 123-126, 11: 91-94, 12: 95-99. 1964.

5 Cooke, William B. Fungi in Sludge Digesters. Proc. 20th Ind. Waste Conf., Purdue Univ. Ext. Ser. 118, 6, 1965.

6 Speece, R.E. and McCarty, P.L. Nutrient Requirements and Biological Solids Accumulation in Anaerobic Digestion. Proceedings of First International Conference on Water Pollution Research, Pergamon Press, London. 1964.

7 Pfeffer, J.T. and White, J.E. The Role of Iron in Anaerobic Digestion. 19th Industrial Waste Conference Bulletin, Purdue University, Lafayette, Indiana. 1964.

7 Kugelman, I.J. and McCarty, P.L. Cation Toxicity and Stimulation in Anaerobic Waste Treatment, II. Daily Feed Studies. 19th Industrial Waste Conference Bulletin, Purdue University Lafayette, Indiana. 1964.

9 Lawrence, A.W., McCarty, P.L., Guerin, F.J., The Effects of Sulfides on Anaerobic Treatment. Proceedings 19th Industrial Waste Conference, Purdue University. 1964.

10 Rudolfs, Willem. Industrial Wastes. 293-294, Reinhold Publishing Company, New York. 1953.

11 Biological Treatment, Sewage and Industrial Wastes. 2, Reinhold Publishing Company, New York. 1958.

12 Buswell, A.M. Methane Fermentation. Proceedings 19th Industrial Waste Conference, Purdue University. 1964.

13 Heukelekian, H. and Heinemann, B. Sewage and Industrial Wastes, 11, 436-444. 1939.

14 Cooper, J.F., Hindin, E. and Dunstan, G.H. Agricultural Ammonia for Stuck Digesters. Proc. 20th Ind. Waste Conf. Purdue Univ. Ext. Ser. 118, 126, 1965.

This outline was prepared by J.C. Dietz, Consultant, Clark, Dietz, and Associates, Urbana, Illinois.

TRICKLING FILTERS

I INTRODUCTION

A Trickling filters have been used for many years for the treatment of municipal liquid biological wastes. Although it is one of the oldest treatment devices, the relationship among the factors affecting the amount of waste removal achieved in a trickling filter has remained obscure.

B Trickling filters are not filters at all, but basically only a pile of rocks providing surface area upon which slime organisms cling and grow. These microbes feed on the dissolved food matter contained in the sewage or industrial waste effluent applied to the filter. When too thick a slime layer accumulates, anaerobic conditions develop at the media surface. A natural mechanism results for cleaning the filter with the periodic "sloughing" of the slime layer from the surface of the filter media. These solids that are sloughed off are collected through final clarification of the filter effluent.

II TRICKLING FILTER COMPONENTS AND THEIR FUNCTIONS

A Distribution - rotary or fixed nozzle

Provides intermittent application, wets all media surfaces, applies sewage effluent uniformly.

B Media

Supports slime, provides slime-sewage-air interfaces, permits ventilation or air flow.

C Underdrainage System

Collects and conveys effluent, admits or draws off air, supports filter media.

D Secondary Clarifier

Settles agglomerated solids and "sloughed" slime growths from final effluent, final clarifier overflow rate varying between 800-1000 gallons per day per square foot (gpd/sq ft).

III ADVANTAGES AND LIMITATIONS OF THE TRICKLING FILTRATION PROCESS

A Advantages

1 Relatively high nitrifying effect upon effluent

2 Low operating cost

3 Ability to function under extreme weather conditions

4 High efficiency in BOD removal

5 High efficiency in suspended solids removal

6 Rugged resistance to shock loads

7 More complex biota than for activated sludge

B Limitations

1 High head losses

2 Odor and fly nuisances

3 Large land area required

4 High initial construction cost

5 Head losses may require pumping

6 Forced ventilation may be necessary

7 Trickling filter effluent clarification may be less complete due to association with anaerobic slime layers.

IV CLASSIFICATION OF TRICKLING FILTERS

A Low Rate or Standard Trickling Filters

1 Hydraulic loading

1-4 million gallon per acre per day (mgad) 25-100 gpd/sq ft

2 Organic loading

220-600 lbs. BOD5/acre-ft/day
5-15 lbs. BOD5/1000 cu ft

3 Recirculation

usually not

4 Filter depth

6-10 ft (ave. 7')

Most of the very early filters were of this type.

B High Rate Trickling Filters

1 Hydraulic loading

4-44 mgad
200-1000 gpd/sq ft

2 Organic loading

660-13,000 lbs. BOD5/acre - ft/day
15-300 lbs. BOD5/1000 cu ft

3 Recirculation

normally provided

4 Filter depth

3-7 ft (ave. 5')

Most of the filters constructed in recent years have been high-rate filters. These filters were built with various depths, and organic loadings.

The performance of biological treatment units of this type is dependent upon the volume of ACTIVE growth present in and on the filter media. The size of the filter and the filter media determine the amount of space available for the growth of the biological slime mass.

The rate of application of the waste influences the amount of growth that will develop. The two types of loading (i.e. organic loading and the volumetric or hydraulic loading) have opposite effects. The greater the amount of available organic matter, the greater the food supply and expected growth. Recirculation increases trickling filter efficiency, however, high dosage rates increase scour, dislodge slime growth, and reduce the volume of active growth present in and on the filter media. It is noted that organic loading has greater influence on trickling filter efficiency than hydraulic loading.

C Super Rate or Roughing Filters

1 Hydraulic loading

up to 1000 mgad

2 Organic loading

(see comment noted below)

3 Recirculation

normally provided

4 Filter depth

up to 40 feet using manufactured plastic filter media instead of rock or stone

This process is usually associated primarily with treatment of industrial wastes.

In some recent filter designs, loads greater than those for the high-rate filters have been used. This is particularly true for manufactured filter media. Presumably the ratio of the useful surface area of the media to the volume of the media is greater for cases in which higher efficiency of BOD removal per unit volume of filter is obtained.

It appears that some allowance, by use of some factor, for the effect of increased surface area within the same volume of manufactured filter media should be made.

V DESIGN CONSIDERATIONS FOR TRICKLING FILTRATION SYSTEMS

A Common Flow Diagrams

1 A general flow diagram which represents most of the possibilities of recirculation of effluents and underflows is shown in Figure 1 could be cut off between the intermediate clarifier and the second stage filter, discarding the second stage filter and final clarifier.

2 Figure 2 shows a few of the more common flow diagrams.

B Factors in Trickling Filter Design

It appears that the efficiency of a trickling filter is dependent upon all or some of the following variables:

1 Composition and characteristics of the waste influent

2 Organic loading to be applied to the filter

3 Pretreatment by sedimentation or other processes

4 Hydraulic loading to be applied to the filter-recirculation ratio and system

5 Filter bed characteristics; volume, area, and depth

6 Type of filter media selected; such as surface to volume of support media and void space

7 If aeration or forced ventilation is to be provided

8 Wastewater and air temperature

C Effects of Recirculation

1 Part of the organic matter in the raw waste feed is brought into contact with the slime organisms more than once.

2 Recirculated effluent contains active microorganisms not found in such quantity in raw waste, thus providing seed continuously.

3 Diurnal organic waste loadings are distributed more evenly.

4 The continuation of waste application to the filter during periods of low flows (night time) precludes long detention periods which may result in septicity. Stale sewage is freshened. Slimes do not dry out.

5 Increased hydraulic loading through recirculation improves uniformity of waste distribution, increases sloughing, and reduces clogging tendencies.

6 Higher velocities and continual scouring also produces conditions less favorable for the growth of filter flies.

7 Continual seeding with active slime organisms and enzymes stimulates hydrolysis and oxidation and increase the rate of biochemical stabilization of the waste.

8 Recirculation will increase operating costs because of the necessary pumping of the return effluent.

9 Wastewater temperatures may be reduced as a result of the number of passes of the liquid through the filter. During cold weather, this may result in decreased biochemical activity and reduced efficiency of treatment provided.

This outline was prepared by J.A. Montgomery, Sanitary Engineer, FWQA Manpower and Training Activities, PNWL, Corvallis, OR.

TRICKLING FILTER FLOW AND RECYCLE

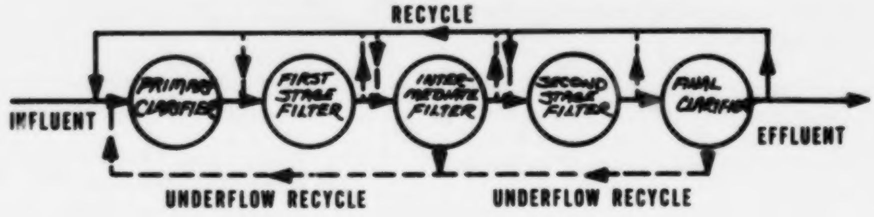

RECYCLE
PRIMARY CLARIFIER
FIRST STAGE FILTER
INTER-MEDIATE FILTER
SECOND STAGE FILTER
FINAL CLARIFIER
INFLUENT
EFFLUENT
UNDERFLOW RECYCLE
UNDERFLOW RECYCLE

FIGURE 1

TRICKLING FILTER FLOW AND RECYCLE

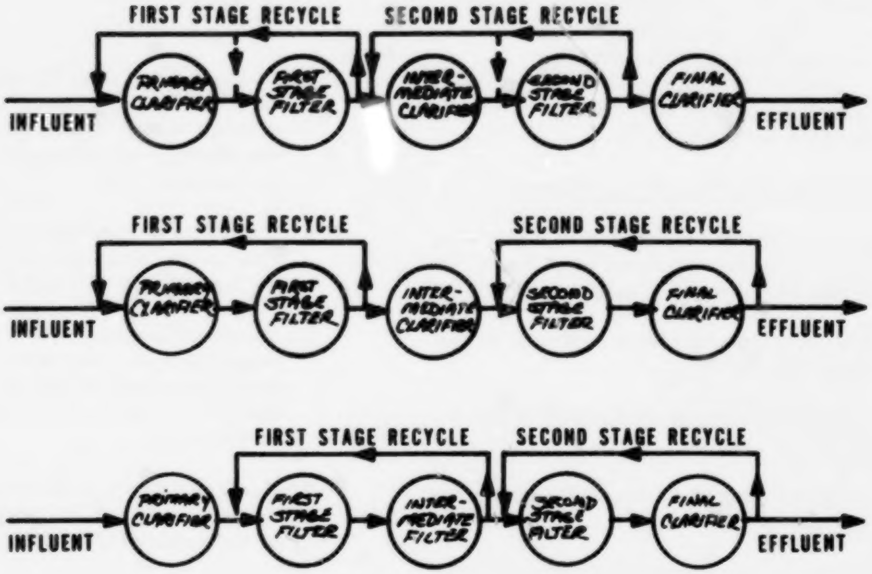

FIRST STAGE RECYCLE
SECOND STAGE RECYCLE
PRIMARY CLARIFIER
FIRST STAGE FILTER
INTER-MEDIATE CLARIFIER
SECOND STAGE FILTER
FINAL CLARIFIER
INFLUENT
EFFLUENT
FIRST STAGE RECYCLE
SECOND STAGE RECYCLE
PRIMARY CLARIFIER
FIRST STAGE FILTER
INTER-MEDIATE CLARIFIER
SECOND STAGE FILTER
FINAL CLARIFIER
INFLUENT
EFFLUENT
FIRST STAGE RECYCLE
SECOND STAGE RECYCLE
PRIMARY CLARIFIER
FIRST STAGE FILTER
INTER-MEDIATE FILTER
SECOND STAGE FILTER
FINAL CLARIFIER
INFLUENT
EFFLUENT

FIGURE 2

AEROBIC DIGESTION

I INTRODUCTION

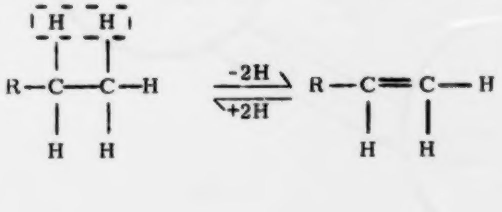
The digestion process, that is the decomposition of organic matter to a non-putrescible and inoffensive state, can occur under either anaerobic or aerobic conditions. It is the purpose of this discussion to present the general concepts and to briefly outline the various aerobic digestion methods.

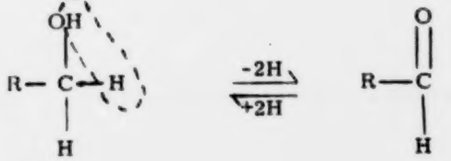
II MECHANISMS OF AEROBIC DIGESTION

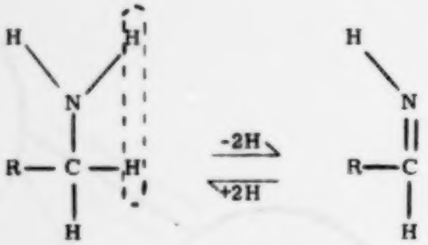
In aerobic digestion, complex organic materials such as fats, proteins, and carbohydrates are decomposed to form simpler products.

The products of hydrolysis and oxidation resulting from aerobic digestion, and the cyclic nature of the component elements (carbon, nitrogen, and sulfur) are shown in Figure 1. Comparison with the cycle for anaerobic digestion (Figure 2) reveals significant differences in the nature of the decomposition products.

Oxidation is defined as the removal of hydrogen, addition of oxygen, or other reaction making the oxidized item more electropositive. The removal of hydrogen is a common first step in decomposition of organic matter as illustrated.







The hydrogen atoms removed combine with oxygen, carbon, nitrogen, or sulfur. Aerobic bacteria utilize oxygen as the hydrogen acceptor. Anaerobic bacteria use "chemically bound oxygen," carbon, nitrogen, or sulfur as the hydrogen acceptor. Facultative bacteria may use both of these but in any case will use the hydrogen acceptor yielding the most energy.

Hydrogen removal follows a definite pattern and is brought about by the coenzymes DPN or TPN. DPN and TPN take up one hydrogen ion and two electrons leaving one free hydrogen ion.

In aerobic microorganisms, DPN H_2 is regenerated by flavin adenosine dinucleotide (FAD). The reaction being:

$$DPNH_2 + FAD \qquad DPN + FADH_2$$

$FADH_2$ is regenerated with oxygen to form water.

$$2FADH_2 + O_2 \qquad 2FAD + 2H_2O$$

III AEROBIC ACTIVITY

It is necessary to have a supply of the proper types of microorganisms, suitable food materials, an oxygen source, and an environment conducive to growth and reproduction.

A Microorganisms

Decomposition of organic waste requires a community consisting of many kinds of organisms:

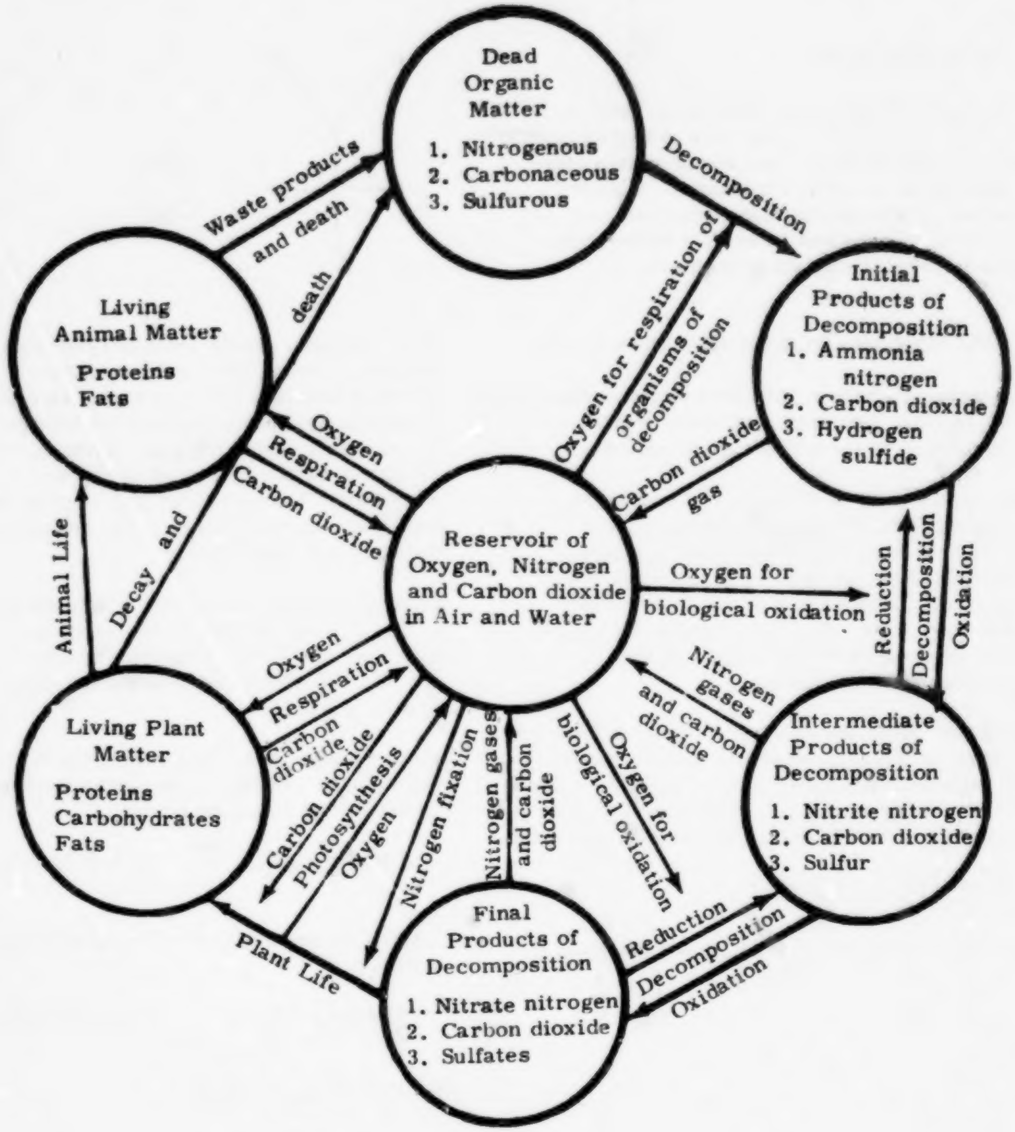

Dead
Organic
Matter
1. Nitrogenous
2. Carbonaceous
3. Sulfurous
Decomposition
Initial
Products of
Decomposition
1. Ammonia nitrogen
2. Carbon dioxide
3. Hydrogen sulfide
Oxygen for respiration of organisms of decomposition
Carbon dioxide gas
Waste products and death
death
Living
Animal Matter
Proteins
Fats
Oxygen
Respiration
Carbon dioxide
Reservoir of
Oxygen, Nitrogen
and Carbon dioxide
in Air and Water
Oxygen for biological oxidation
Reduction
Decomposition
Oxidation
Animal Life
Decay and
Oxygen
Respiration
Carbon dioxide
Nitrogen gases and carbon dioxide
Intermediate
Products of
Decomposition
1. Nitrite nitrogen
2. Carbon dioxide
3. Sulfur
Living Plant
Matter
Proteins
Carbohydrates
Fats
Carbon dioxide
Photosynthesis
Oxygen
Nitrogen fixation
Nitrogen gases and carbon dioxide
Oxygen for biological oxidation
Final
Products of
Decomposition
1. Nitrate nitrogen
2. Carbon dioxide
3. Sulfates
Reduction
Decomposition
Oxidation
Plant Life

FIGURE 1. Cycle of nitrogen, carbon, and sulfur in aerobic decomposition.

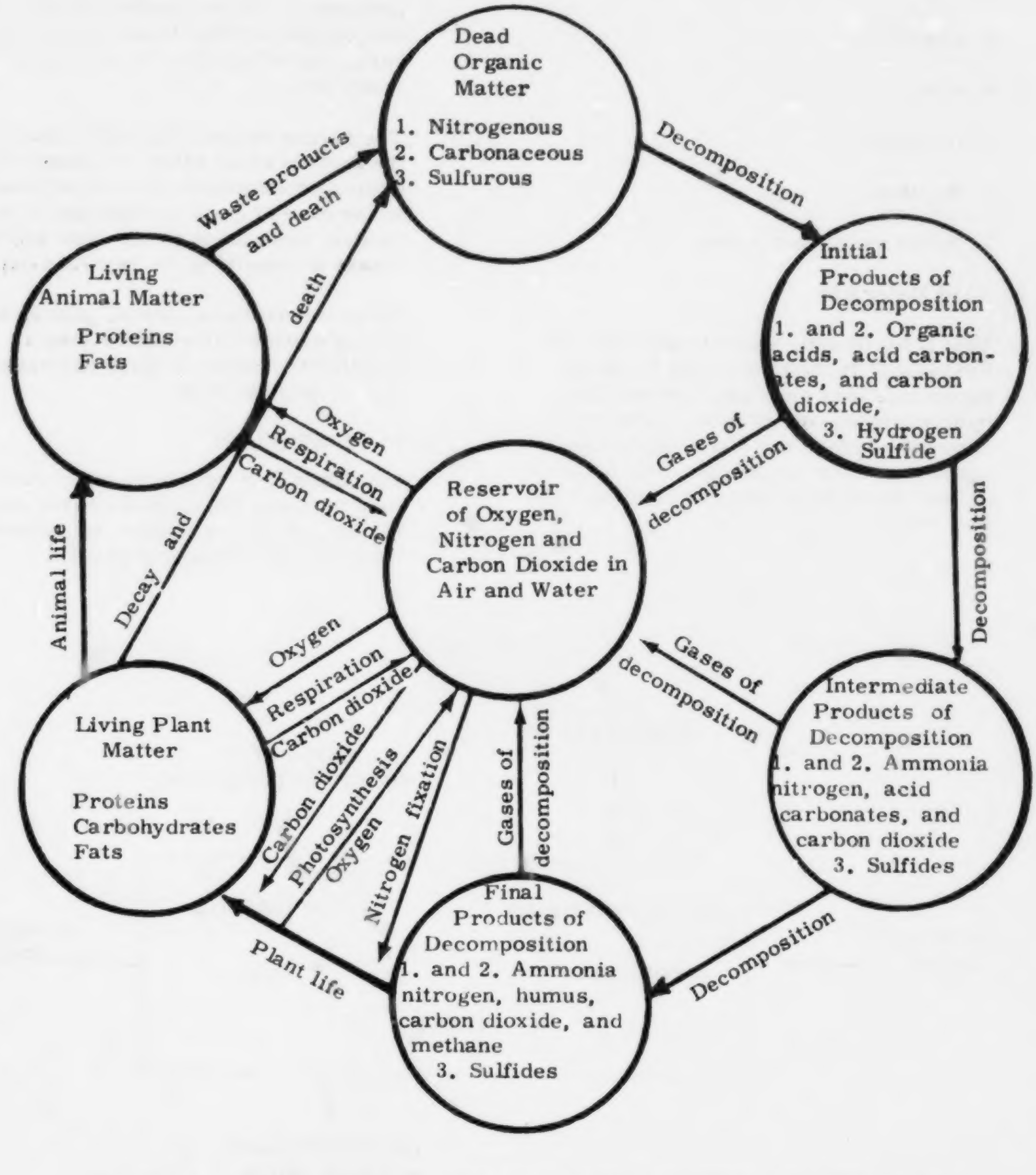

Dead
Organic
Matter
1. Nitrogenous
2. Carbonaceous
3. Sulfurous
Decomposition
Initial
Products of
Decomposition
1. and 2. Organic
acids, acid carbon-
ates, and carbon
dioxide,
3. Hydrogen
Sulfide
Decomposition
Intermediate
Products of
Decomposition
1. and 2. Ammonia
nitrogen, acid
carbonates, and
carbon dioxide
3. Sulfides
Decomposition
Final
Products of
Decomposition
1. and 2. Ammonia
nitrogen, humus,
carbon dioxide, and
methane
3. Sulfides
Plant life
Living Plant
Matter
Proteins
Carbohydrates
Fats
Animal life
Living
Animal Matter
Proteins
Fats
Waste products
and death
Decay and death
Reservoir
of Oxygen,
Nitrogen and
Carbon Dioxide in
Air and Water
Oxygen
Respiration
Carbon dioxide
Oxygen
Respiration
Carbon dioxide
Carbon dioxide
Photosynthesis
Oxygen
Nitrogen fixation
Gases of
decomposition
Gases of
decomposition
Gases of
decomposition

FIGURE 2. Cycle of nitrogen, carbon, and sulfur in anaerobic decomposition

1 Bacteria

2 Molds

3 Yeasts

4 Algae

5 Protozoa

6 Rotifera

7 Worm and insect larvae

B Food Materials

Nearly all organic wastes may serve as food supply for the community. Some exceptions may be organic pesticides, hydrocarbons, and ethers. It has been shown, however, that even highly toxic materials, such as phenols, can be used as food if the community is acclimated to the waste.

C Oxygen Source

The oxygen source is generally the atmosphere but the method of introducing this oxygen into the waste stream will vary, depending upon the method of treatment.

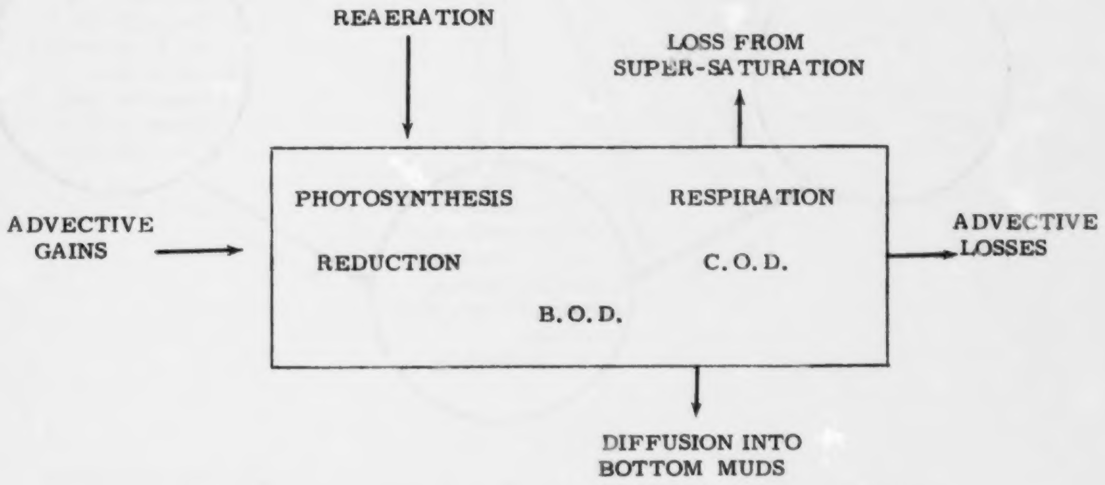
The oxygen budget (Figure 3) illustrates the factors which affect the dissolved oxygen concentration in a water mass. In the case of aerobic digestion of organic wastes, reaeration is the most significant means of supplying the required oxygen.

In natural streams, lakes, ponds, and bays photosynthesis can become a significant source of dissolved oxygen during daylight hours.

D The Environment

Important environmental factors include: temperature, pH, organic waste concentration, presence of toxic substances, and substrate for biological growth.

FIGURE 3


REAERATION
LOSS FROM SUPER-SATURATION
ADVECTIVE GAINS
PHOTOSYNTHESIS
RESPIRATION
REDUCTION
C. O. D.
B. O. D.
ADVECTIVE LOSSES
DIFFUSION INTO BOTTOM MUDS

DISSOLVED OXYGEN
OF A
WATER MASS

1 Temperature has an effect on the rate of biological activity as well as being a determining factor in the types of organisms which will thrive. The range at which mesophilic microorganisms thrive is up to 110° F; the thermophilic range extends above 110° F with optimum activity at 130° F. Activity decreases rapidly below about 10° C but is detectable at 1° C.

2 pH

A pH range of 6.0 to 8.5 is considered desirable.

3 Concentration of waste

Abnormally high concentrations of wastes may be intolerable over an extended period. The result of overload is usually the development of anaerobic conditions.

4 Toxic materials

Very dilute concentrations of toxic materials can usually be tolerated by at least some of the organisms living in the community. As these types become prevalent it is not uncommon to find that they decompose the toxic material.

5 Substrate

Substrates used to provide suitable environmental conditions for development of a community of microorganisms vary with the type of treatment facility. In the trickling filter, the substrate is the rock or filter media; in the activated sludge plant the substrate is the floc which in itself is a colony of microorganisms.

IV AEROBIC TREATMENT METHODS

A Activated Sludge

Activated sludge is a process into which sufficient air is added to maintain aerobic conditions during the treatment process. The culture substrate is composed of small floc particles of decomposing organic matter and bacteria.

B Trickling Filter

The trickling filter maintains aerobic conditions through counter-current flow of air upward through the filter stone as the waste trickles downward over the bacterial colonies attached to the filter media.

C Stabilization Pond

Aerobic conditions in a stabilization pond depend upon reaeration through the surface, wind action in both dissolving oxygen into the water mass and for mixing. Photosynthesis may be important in daylight hours as a source of dissolved oxygen.

V SUMMARY

A The final products of aerobic digestion are:

1 Carbon dioxide

2 Nitrate nitrogen

3 Sulfates

4 Water

5 Residues of relatively stable substances

B Decomposition proceeds by the removal of hydrogen from the organic wastes. This hydrogen may combine with:

1 Oxygen to form water

2 Nitrogen to form ammonia

3 Carbon to form methane

4 Sulfur to form hydrogen sulfide

In aerobic digestion, the predominate hydrogen acceptor is oxygen, with nitrogen, carbon, and sulfur proceeding to form NO_3^-, CO_2, and $SO_4^=$ during decomposition of organic matter. Hydrogen acceptors during anaerobic degradation include carbon to form methane and oxygen to form water.

C A suitable environment must be provided to stimulate the growth and reproduction of a biological community. Such an environment may be provided for treatment of organic wastes in:

1 A trickling filter

2 Activated sludge

3 Stabilization ponds

REFERENCES

1 Babbitt, H. E., Sewerage and Sewage Treatment, John Wiley & Sons, New York, (1953).

2 Fair, G. M. and Geyer, J. C., Water Supply and Waste-Water Disposal, John Wiley & Sons, New York, (1966).

3 Gurnham, C. F., Principles of Industrial Waste Treatment, John Wiley & Sons, New York, (1955).

4 McKinney, R. E., Microbiology for Sanitary Engineers, McGraw-Hill, New York, (1962).

5 Rich, L. G., Unit Processes of Sanitary Engineering, John Wiley & Sons, New York, (1963).

This outline was prepared by L. J. Nielson, Sanitary Engineer, FWQA Training Activities, PNWL.

DESIGN OF BIOLOGICAL OXIDATION SYSTEMS

ACTIVATED SLUDGE

I VARIABLES TO BE CONSIDERED

A BOD Removal Characteristics for Specified Operating Conditions

B Oxygen Requirements for Various Loading Levels

C Sludge Production

D Nutritional Requirements

E Oxygen Transfer and Aeration

F Solids - Liquid Separation

G pH, Temperature and Toxicity Effects

II BOD REMOVAL CHARACTERISTICS

A BOD is removed by several mechanisms - adsorption, coagulation, diffusion and enzymatic activity. Removal is related to sludge growth. Type of reaction depends on concentration, nature of substrate. (See Figure 1.

B The various relationships applicable to activated sludge data correlation are (see Figure 2):

	Conditions	BOD Removal Equation	Remarks
1	High BOD Wastes	$2.3 \log (1 + \frac{aL_r}{S_o}) = K_1 t$	applicable when the initial BOD/sludge solids ratio exceeds 2; applies only when BOD removal is independent of BOD concentration usually at BOD levels above 200-300 mg/l.
2	High BOD Wastes (Zero order reaction)	$\frac{L_r}{Sa \cdot t} = \frac{K_1}{a}$	applicable when initial BOD sludge ratio is less than 2. Same limitations as Equation (1). Also applicable to removal of specific substrate such as phenol.
3	Low BOD wastes (1st order reaction)	$\frac{L_r}{L_o} = (1 - e^{-K_2 S_a t})$	describes course of BOD removal for simple substrates with initial BOD's less than 300 mg/l
4	Composite exponential	$L = L_a e^{-(K_2)_a Sa.t} + L_b e^{-(K_2)_b Sa.t} + L_b e^{-(K_2)_n Sa.t}$	

	Conditions	BOD Removal Equation	Remarks
5		$\frac{dL}{dt} = \frac{K_2}{(1 + mSa.t)} L$ which integrates to: $\frac{L}{L_o} = (1 + mSa.t)^{-K_2/m}$	equations 4, 5, 6 and 7 estimate BOD removal from complex waste substrates in which the removal rate decreases with time or concentration.
6		$\frac{1}{Sa} \frac{-dL}{dt} = K_2 \frac{(L)^n}{(L_a)} L$ which integrates to: $\frac{L}{L_o} = \left(\frac{1}{(1 + nK_2Sa.t)}\right)^{1/n}$	
7		$\frac{L}{L_o} = \frac{1}{1 + K_2Sa.t}$	
8	Completely mixed systems	$L_r = \left(- \frac{dL}{dt}\right) . t$	may not apply in all biological systems since biological populations in complete mixing may differ from plug flow.

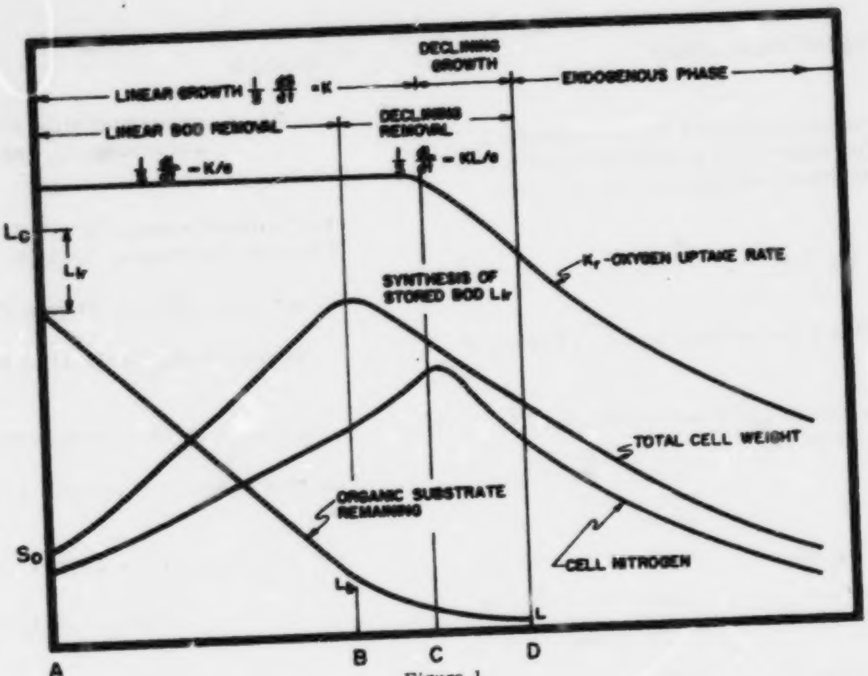


Figure 1

SCHEMATIC REPRESENTATION OF BOD REMOVAL, SLUDGE GROWTH AND SLUDGE OXIDATION

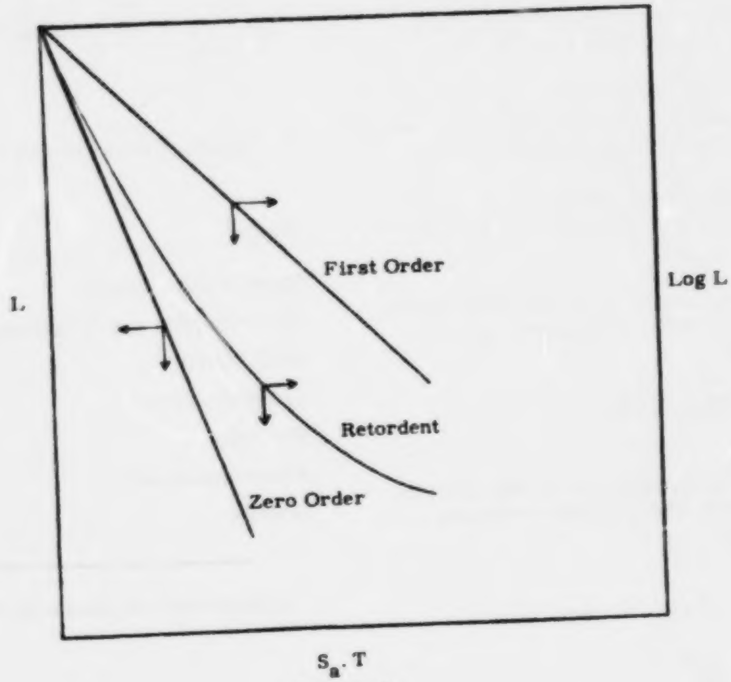


Figure 2

III OXYGEN UTILIZATION

A Oxygen requirements for two functions; provide energy for growth; for basic cell maintenance (endogenous respiration)

$$O_2 = \underline{a}' L_r + b S_a$$

$\underline{a}'$ varies with nutrient level. (Figure 3)

B Typical Values of Coefficient $\underline{a}'$ and b' based on BOD_5

Waste	$\underline{a}'$	b'
Spent Sulfite liquor	0.40	0.17
Mixed pulp and paper	0.48	0.06
Board Mill	0.33 - 0.40	-
Synthetic fibre	0.55	0.14
Pharmaceutical	0.35	0.25

C Variation in oxygen utilization through aeration tank depends on initial loading ratio Lo/So and on flow distribution.

1 High Lo/So - uptake rate, K_r remains constant until substrate nearly exhausted then decreases to endogenous level.

2 Low Lo/So - rapid decrease in K_r as substrate is exhausted to endogenous level.

3 Completely mixed or cross-flow tanks - uptake rate equal throughout tank. (Figure 4)

IV SLUDGE PRODUCTION

A Removal of BOD results in sludge growth. Inert volatile solids in waste increase excess sludge.

$$\Delta S = aL_r - bSa + I$$

in which

ΔS = excess volatile solids accumulation, lbs/day

For soluble wastes "a" ~ COD removed (Servizi and Bogan, 1963; McCarty 1964).

a = gms VSS = 0.39 gms COD removed

or on a BOD_5 basis when $K_{bod} = 0.1$

a = gms VSS = 0.57 gms BOD_5 removed.

On this basis, cell synthesis from glucose is:

$$6\ C_6H_{12}O_2 + 17O_2 + 4NH_3 = 4\ C_5H_7NO_2 + 17CO_2 + 30H_2O$$

In industrial wastes, "a" varies due to:

1 presence of non-oxidizable solids

2 variation in the BOD k rate

3 variations in endogeneous respiration rate

B Typical Values of Coefficient a

Waste	a(BOD_5)
Spent sulfite liquor	0.55
Kraft pulping and bleaching	0.50
Wall board	0.7 - 0.78
Synthetic fibre	0.38
Refinery	0.70
Pharmaceutical	0.77
Sewage	0.49 - 0.64

typical data is shown in Figure 5.

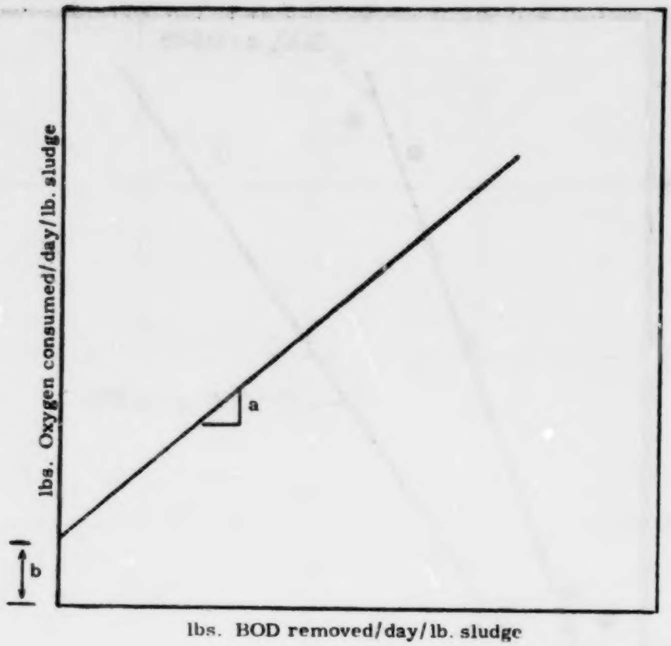


Figure 3

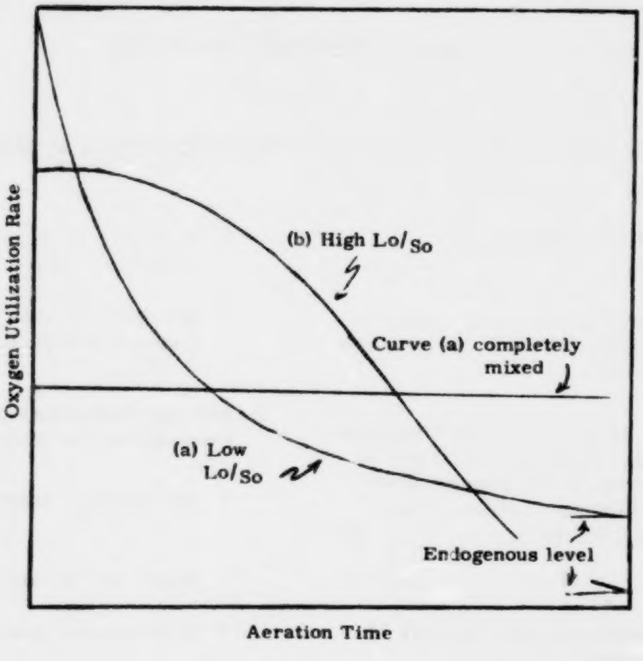


Figure 4

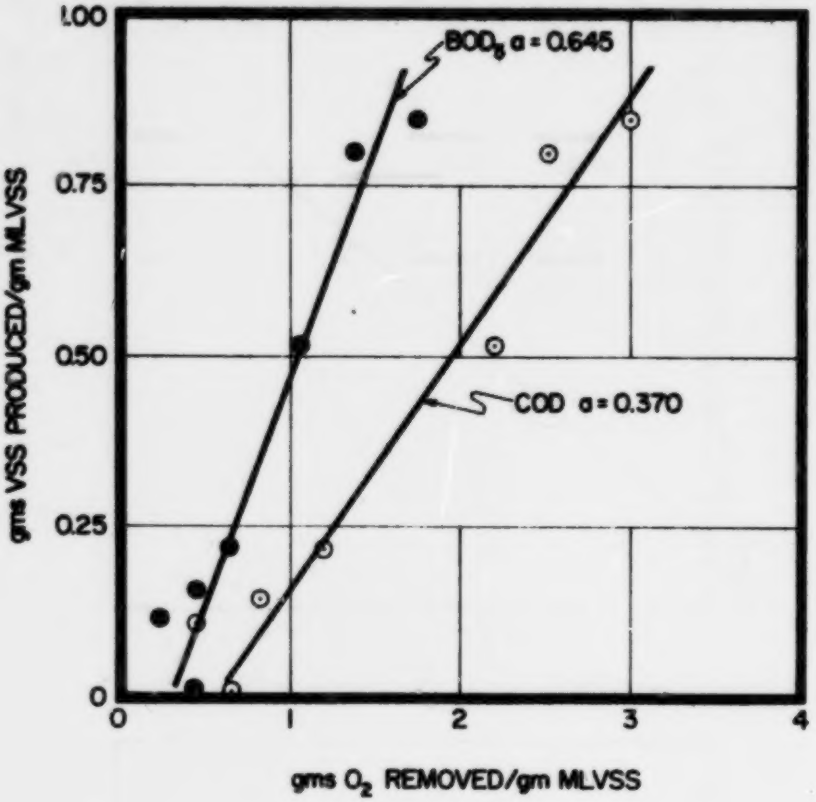


Figure 5

CELL SYNTHESIS FROM A SOLUBLE PHARMACEUTICAL WASTE

V NUTRITIONAL REQUIREMENTS

A Bio-oxidation requires minimal quantities of nitrogen and phosphorus; must be added to deficient wastes.

Nitrogen content of cell based on empirical formula $C_5H_7NO_2$ is 12.3%. Nitrogen is usually expressed as a fraction of mixed liquor volatile suspended solids. This may vary from 12.3% due to:

1 presence of oxidized cells (occurs at low organic loading levels).

2 presence of inert volatile solids (e.g. cellulose, fibre, etc.)

3 presence of absorbed or stored organics (occurs at high loading levels).

B Average Quantities of Nitrogen and Phosphorus for Most Industrial Wastes

1	lbs/100 lbs. BOD removed	4.0 lbs N 1.0 lbs P
2	BOD : N : P ratio	100 : 5 : 1
3	% of volatile sludge solids	7.0 N 1.2 P

C A portion of N and P resolubilized during auto-oxidation; available for reuse.

VI OXYGEN TRANSFER AND AERATION

A Oxygen absorption in water occurs according to the relationship

$$N = K_L A (C_s - C_L)$$

or

$$dc/dt = K_L a (C_s - C_L)$$

B Factors Affecting Absorption:

1 Characteristics of diffusion devise defined by oxygen transfer coefficient $K_L a$

2 Driving force defined by difference between saturation at mid-tank depth and operating dissolved oxygen level $(C_s - C_L)$

3 Temperature of aeration liquid defined by the relationship:

$$K_L a_{(t^oC)} = K_L a_{(20^oC)} \, 1.02^{(T-20)}$$

4 Waste characteristics including presence of surface active agents and organics which increase or decrease absorption coefficient; defined by

$$\alpha = \frac{K_L a \text{ waste}}{K_L a \text{ water}}$$

under aeration conditions.

C Types of Aeration Units

1 Diffused or bubble aerators

2 Turbine aerators

3 Surface aerators

D Diffused Aeration

1 Diffused aeration; variation in oxygen transfer efficiency of 8.0 - 13.7% depends on type of diffuser, air flow rate, aeration tank geometry.

2 Diffuser performance correlated according to relationship:

$$N = C\, G_s^n h^{0.7} \alpha (C_{sw} - C_L) \cdot 1.02^{(T-20)} \cdot \beta$$

E Turbine Aerators

1 Turbine aerators employ submerged agitator with air discharged beneath through a sparge ring; oxygen transfer efficiency 20-35%; oxygen transfer 2.3-2.8 lbs. O_2/hp hr.

2 Turbine performance correlated according to the relationship:

$$N = C\, C_s^m R^m D^p \alpha (C_{sw} - C_L)\, 1.02^{(T-20)}$$

F Surface Aerators

1 Surface aerators which discharge or spray liquid over the tank surface for oxygen entrainment and absorption.

2 Commercial units transfer 2.5 - 4.0 lbs. O_2/hp hr.

$$N = N_o \frac{C_{sw} - C_L}{C_s} \cdot 1.02^{(T-20)} \cdot \alpha$$

VII SOLID-LIQUID SEPARATION

A Activated sludge separation from mixed liquor by sedimentation or flotation.

B Sedimentation area requirements for:

1 Clarification in which the rise velocity of the liquid overflowing is less than sludge settling velocity.

2 Sludge thickening in which area requirements are dependent on the thickening characteristics of the sludge. In activated sludge practice thickening usually determines surface area.

C Design criteria - unit area ft^2 of surface/lb. solids/day determined from laboratory settling tests using relationship:

$$U.A. = 0.67 \frac{(1/C_2 - 1/C_u)}{V_2}$$

in which C_u = desired under flow concentration, gms/l

V_2 = settling velocity of sludge interface at compression point, ft/hr.

C_2 = interfacial sludge concentration at compression point, gms/l

$$C_2 = \frac{C_o H_o}{H_i}$$

C_o = initial sludge concentration, gms/l

H_o = initial height of settling cylinder

H_1 = height in settling cylinder of tangent to compression point extended to y axis

A typical example is shown in Figure 6.

D Sedimentation Design Should Consider:

1 Maximum concentration of sludge by thickening

2 Biological properties of sludge, i.e., gasification, dentrification

E Dissolved air flotation can be employed for mixed liquor separation or sludge thickening; variables to be considered; recycle ratio, pressure.

F Design parameters for flotation - air/solids ratio and overflow rate. Components of system; pressurizing pump, air injection facilities, retention tank, back pressure regulating device and flotation unit. Air/solids ratio ranges from 0.015-0.06 lbs. air/lb. solids for sewage activated sludge.

Air/solids ratio computed from the relationship:

$$A/S = \frac{1.2sa \quad (f'P - 1)R}{Sa \cdot Q}$$

in which sa = air solubility at standard conditions in cc/l

f' = fraction of air dissolved at pressure P

P = pressure in atmospheres

R = pressurized recycle in mgd

Sa = sludge solids in mg/l

Q = mixed liquor flow, mgd

G Typical Operating Conditions:

Overflow rate	1.5 - 4.0 mg/l/ft^2
Retention period	20 - 30 min.
Pressure	40 - 60 psig
Recycle	25 - 200%

VIII pH AND TEMPERATURE EFFECTS

A pH to be considered that of mixed liquor not raw waste; for most wastes effective range pH 6.0 - 8.5.

B Alkaline wastes - OH reacts with CO_2 from respiration; system buffers at pH 8.3.

C Acid wastes - organic acid breakdown and neutralization results in production of bicarbonate buffer at pH 8.3.

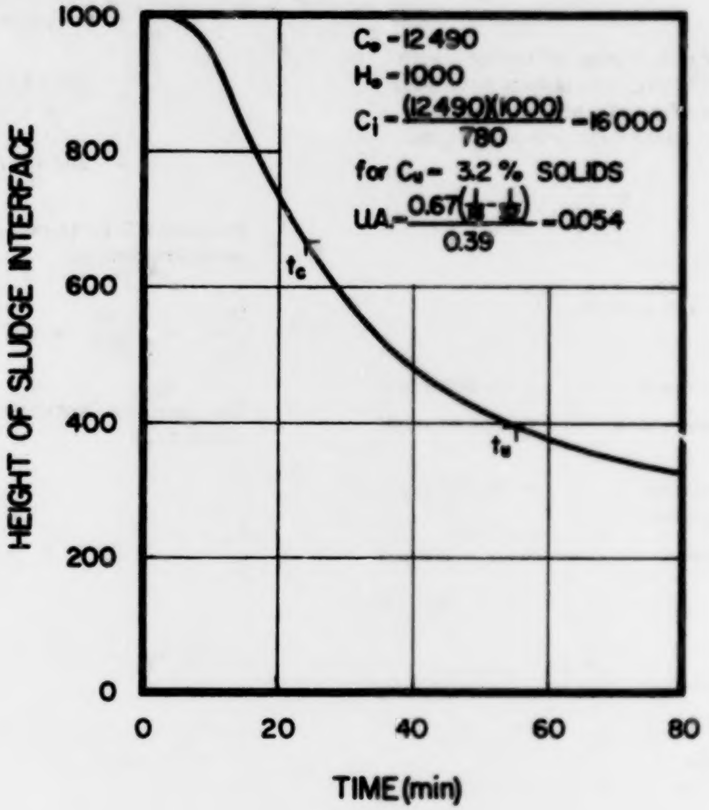


Figure 6

CALCULATION OF THICKENER AREA

D Effective temperature range for most systems 10 - 35°C; oxygen utilization increases according to relationship

$$K_{T_1}/K_{T_2} = 1.065^{(T_2 - T_1)}$$

E Activated sludge at low loading less influenced by temperature; mass transfer controls rate.

F Reduction in process efficiency at high temperatures (< 35°C); thermophilic activity.

PROBLEM

It is desired to treat 5.0 mgd of a waste with an initial BOD of 250 mg/l to obtain 90% BOD reduction. The coefficients and parameters obtained from pilot plant data are as follows:

1 BOD removal:

$$\frac{L_e}{L_o} = \frac{1}{1 + 1.25\, Sa \cdot t}$$

2 Settled sludge return = 12,000 mg/l

Mixed liquor suspended solids = 2,500 mg/l

Mixed liquor volatile suspended solids = 2,100 mg/l

Nitrogen in waste = 3 mg/l

Phosphorus in waste = 2 mg/l

3 Value of coefficients

Ratio of oxygen to sludge volatile solids = 1.25

a = 0.55

a' = 0.40

b = 0.10

b' = 0.125

a Aeration tank volume

Sludge recycle ratio: From a material balance of the aeration system (neglecting suspended solids in the influent waste), the sludge recycle ratio can be defined.

$$r = \frac{S_a}{S_r - S_a} = \frac{2500}{12000 - 2500} = 0.26$$

Sludge recycle, $r = (0.26)(5.0) = 1.3$ mgd

BOD in aeration tank at start of aeration:

$$L_o = \frac{L_a + r L_e}{1 + r}$$

$$= \frac{250 + (0.26)(25)}{1 + 0.26}$$

$$= 203 \text{ mg/l}$$

Required % BOD remaining in the aeration tank is

$$\frac{L_e}{L_o} = \frac{25}{203} = 0.123$$

The required solids-time product is computed:

$$\frac{L_e}{L_o} = 0.123 = \frac{1}{1 + 1.25\, Sa \cdot t}$$

$$\therefore\ Sa \cdot t = 5.7 \times 10^3$$

For a mixed liquor solids of 2500 mg/l $t = 2.3$ hours

Volume of aeration tank

$$(5.0 + 1.3)\text{ mgd} \cdot \frac{2.3}{24} = 0.6 \text{ mg} - 80,000 \text{ ft}^3$$

b Oxygen requirements

The average oxygen requirements are determined from the relationship:

$$\text{lbs } O_2\text{/day} = 0.40 \text{ lbs } BOD_r\text{/day} + 0.125 \text{ lbs MLVSS}$$

$$= 0.40\,(5.0 \cdot 250 \cdot 8.34 \cdot 90) + (0.125 \cdot 0.6 \cdot 8.34 \cdot 2100)$$

$$= 5050 \text{ lbs/day or } 210 \text{ lbs/hr.}$$

The average utilization rate is (r_r)

$$r_r = \frac{\text{lbs. } O_2/\text{hr}}{8.34 \cdot V} = \frac{210}{8.34 \cdot 0.6}$$

$$= 42 \text{ mg/l/hr}$$

The variation in uptake rate will depend upon the initial BOD/solids ratio and on the degree of mixing in the aeration tank.

c Three aeration designs will be considered; diffused aeration employing tapered aeration and turbine and surface aeration employing homogeneously mixed tanks.

1) Diffused aeration

The aeration data defined for design conditions is

Temperature = 30°C
α waste = 0.6
α effluent = 0.95
C_s = 8.6 mg/l*

---

*computed as saturation at the aeration tank mid-depth.

Oxygen Utilization Distribution

Tank quarter	% of total O_2
1	55
2	18
3	15
4	12

The oxygen requirement for the first quarter of the aeration tank is $0.55 \cdot 210 = 116$ lbs. O_2/hr

The transfer ration, α, for the raw waste and the treated effluent is 0.6 and 0.9 respectively. Neglecting longitudinal mixing, the average at the inlet of the tank will be:

$$\alpha \text{ (inlet)} = \frac{(1 \times 0.6) + (0.26 \times 0.9)}{1.26} = 0.66$$

The performance of the selected air diffuser is:

$$N = 0.0026\, G_s^{0.85} h^{0.7} \cdot (C_{sw} - C_L)\ 1.02^{(T-20)} \cdot \alpha$$

Table 1. AIR DIFFUSER SPACING CHART

Section	# of diffusers	#O_2/hr	Spacing	α
1	188	116	2 rows - 7-1/2"℄	0.71
2	53	38	1 row - 12"℄	0.77
3	39	32	1 row - 17"℄	0.86
4	30	25	1 row - 22"℄	0.90

The required aeration volume is 80,000 ft^3; using a liquid submergence depth of 15 ft. and a tank width of 25 ft., required tank length is 215 ft. Each tank quarter is therefore 55 ft.

For an air flow (G_s) of 8 scfm/diffuser unit and a submergence depth (h) of 15 ft.

$$N = 0.0026(8)^{0.85}(15)^{0.7}(8.6 - 1.0) \cdot 1.02^{10} \cdot 0.66$$

$$= 0.615 \text{ lbs. } O_2/\text{hr/unit}$$

No. of units = 116/0.615 - 188

spacing = 55 ft./188 = 0.3 ft.

Results of similar calculations for other quarters of the tank are listed in Table 1.

2) Turbine aeration

The aeration conditions are the same as (1) diffused aeration. In this case, however, it will be assumed that the oxygen uptake rate is equalized throughout the tank length at an average rate of 42 mg/l/hr. The aeration tank is selected as 42 × 15 × 127 ft. Three turbine aerators will be employed in 42 ft. square sections. The oxygen transfer characteristics at the turbine aerator are expressed by the relationship:

$$N = 0.00156\, G_s^{0.45}\, R^{1.5} d^{1.8}$$

$$\alpha (C_{sw} - C) \cdot 1.02^{(T-20)}$$

Using a turbine diameter of 4.0 ft. and a peripheral speed of 10 ft/sec the required air flow for each turbine is computed:

$$\frac{70}{0.00156 \cdot 10^{1.15} \cdot 4^{1.8} \cdot (8.6 - 1.0) \cdot 0.85 \cdot 1.22}$$

$$= G_s^{0.45}$$

$$G_s = 210 \text{ scfm}$$

The horsepower for the above turbine is defined by the relationship:

$$HP = 0.02 d^{5.25} n^{2.75}$$

$$HP = (0.02)(4)^{5.25}(0.76)^{2.75}$$

$$= 15.7$$

It should be noted that the operating horsepower under aeration will decrease due to the decreased density of the aeration mixture. The total horsepower will be the sum of both the turbine horsepower and the blower horsepower.

3) Surface aeration

It has been found that a surface aerator will transfer 3.5 lbs. O_2/hp hr. in water at 20°C, zero dissolved oxygen. Using an aeration tank 35 ft. wide, 12 ft. deep and 200 ft. long, 6 units may be employed:

$$N = 3.5\, \frac{(8.6 - 1.0)}{9.1} \cdot 0.85 \cdot 1.22$$

$$N = 3.0 \text{ lbs. } O_2/\text{hp hr.}$$

$$\frac{210 \text{ lbs. } O_2/\text{hr}}{3.0 \text{ lbs. } O_2/\text{hp hr}} = 70 \text{ hp}$$

$$\text{Each unit} = \frac{70}{6} = 11.7 \text{ hp}$$

Sludge production

The quantity of biological sludge which will be produced can be determined from:

(lbs VSS/day)

$$S = 0.55 \text{ lbs BOD}_r/\text{day} - 0.10 \text{ lbs. MLVSS}$$

$$= 0.55\,(9400) - 0.10\,(10{,}500)$$

$$= 4{,}110 \text{ lbs/day}$$

lbs TSS @ 84% volatile = 4900 lbs/day

Sludge loss in effluent at 30 mg/l = 1250 lbs/day

net for disposal = 3650 lbs/day

Nutrient requirements

To provide 7% nitrogen in the biological volatile solids for average operating conditions:

nitrogen required = (4110 lbs/day VSS) (0.07) = 288 lbs/day

nitrogen in waste = (3.0) (5.0) (8.34)

= 125 lbs/day

163 lbs/day

Phosphorous requirements may be similarly computed.

Secondary sedimentation

The settling characteristics of the biological sludge are shown in Figure 6.

From Figure 6

V_2 = 1.14 ft/hr

$C_oH_o = C_2H_1$

$(2090)(1000) = (C_2)(430)$

C_2 = 4870 mg/l

C_u = 12,000 mg/l

$$U.A. = \frac{0.67\left(\frac{1}{C_2} - \frac{1}{C_u}\right)}{V_2}$$

$$U.A. = \frac{.67\left(\frac{1}{4.87} - \frac{1}{12}\right)}{V_2}$$

$$= \frac{0.67\left(\frac{1}{4.87} - \frac{1}{12}\right)}{1.14}$$

$$= .072 \text{ ft}^2\text{/lb solids/day}$$

The solids per day entering the settling tank is 6.3

6.3 mgd 2500 mg/l · 8.34

= 131,000 lbs/day

Total surface area of settling tanks is

$131,000 \cdot 0.072 = 9450 \text{ ft}^2$

This outline was prepared by W.W. Eckenfelder, Professor of Sanitary Engineering, Department of Civil Engineering, University of Texas, Austin, Texas 78712.

AERATED LAGOON

Variables to be considered same as activated sludge; temperature effect more pronounced.

I DESIGN PROCEDURE

A Determination of BOD Removal Rate

BOD removal rate with or without nutrients can be determined in the laboratory by batch aeration of waste, seeded with an acclimitized effluent. Alternately, continuous treatment in a drum or pilot basin can be employed to develop a removal curve. The relationship obtained will frequently be a retardant type reaction in which the removal rate decreases with time or concentration. The removal rate should be determined at several temperatures and the temperature coefficient computed according to the relationship $K_t = K_{20^o} \cdot \theta^{(T-20)}$ in which K is the BOD removal rate coefficient.

II REQUIRED LAGOON VOLUME

A Because of the high temperature dependence, the basin volume required should be computed for both summer and winter temperature conditions. For this purpose the estimated basin temperature must be computed. This is determined from a heat balance under various ambient temperature conditions. Heat is lost through evaporation, convection and radiation and is gained by solar radiation. It has been found that heat loss by evaporation and heat gain by solar radiation are small compared to the losses by convection and radiation and can be neglected.

The heat loss by convection can be computed from the relationship:

$$H_c = (0.8 + 0.32\ W/2)\ (T_w - T_a) \quad (1)$$

in which T_w and T_a are the lagoon and air temperatures respectively and W the mean wind velocity.

The heat loss by radiation can be expressed by the relationship:

$$H_r = 1.0\ (T_w - T_a) \quad (2)$$

Combining equations (1) and (2) and employing a surface turbulence correction the heat balance around the lagoon can be expressed:

$$f\int A\ (T_w - T_a) = Q\ (T_i - T_o) \quad (3a)$$

in which A is the total surface area, Q the waste flow and T_i and T_o the influent and effluent temperature of the lagoon respectively. Since in a completely mixed basin $T_o = T_w$, equation 3a can be reexpressed to determine the mean basin temperature.

$$(T_i - T_w) = \frac{(T_w - T_a)\ f\ A}{Q} \quad (3b)$$

When Q is expressed in mgd and A in square feet, f has an approximate value of 12×10^{-6} for the central portion of the United States. In computing the estimated lagoon temperature, local weather bureau records are employed to define T_a.

B For each estimated liquid temperature, the retention period for the required removal is computed. The volume of the lagoon is then calculated. The largest volume computed will control the design.

C A preliminary selection of lagoon dimensions is made. For most cases, a depth of 6 to 12 feet is suggested. It is generally

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desirable to divide the required volume into at least 2 basins for operational flexibility.

III OXYGEN REQUIREMENTS

A From the laboratory or pilot plant data, the BOD removal is plotted against the oxygen uptake rate.

$$\text{lbs. } O_2/\text{day} = a' \text{ lbs. BOD removed/day} \quad (4)$$

B The coefficient, a', in equation (4) is calculated from the slope of this line.

C The pounds of oxygen per day for the specified BOD removal is computed from equation (4).

IV DESIGN OF AERATION SYSTEM

A Surface Aeration

Surface aeration results from surface turbulence and wave action and can be related to the mean velocity gradient at the surface. Where experimental data is available the mean surface velocity gradient can be computed. If no data is available, an average value of 1-4/sec for mechanical surface aerators can be employed resulting in an oxygen transfer of 300-700 lbs. O_2/hr/m ft^2 at 20°C, O DO, in water. (The high value would apply for closer aerator spacing.) C_L is usually taken as 1.5 ppm dissolved oxygen. The total oxygen transferred is N_A.

B Mechanical Aeration

The oxygen required to be transferred by mechanical aeration can be computed,

$$N_M = N_T - N_s$$

where

N_M = lbs. O_2/hr by mechanical aeration

N_T = total lbs. O_2/hr

N_s = lbs. O_2/hr by surface aeration

The oxygen transfer by the mechanical aeration units for specified lagoon operating conditions is computed from the relationship:

$$N = N_o \frac{C_{sw} - C_L}{C_s} \cdot 1.02^{(T-20)} \cdot \alpha \quad (5)$$

in which N = oxygen transferred for hp hr under lagoon operating conditions

N_o = oxygen transferred per hp hr in water at 20°C and O DO

C_{sw} = saturation of oxygen in the lagoon contents at temperature, t, ppm

C_L = dissolved oxygen level in the lagoon, ppm

C_s = saturation in water at 20°C, ppm

t = lagoon temperature, °C

α = oxygen transfer ratio of waste to water

The number of aeration units depends in part on the selected basin geometry and the horsepower per unit. From data presently available, maximum spacing should be of the order of 200 - 250 ft. The horsepower per aeration unit

$$HP = \frac{N_M}{n \cdot N}$$

V NUTRIENTS

Optimum treatment should result from a nutrient availability of:

4.0 lbs N/100 lbs BOD removed

0.6 lbs P/100 lbs BOD removed

EXAMPLE

Design an aeration lagoon to obtain 80% BOD reduction during the summer (mean air temperature 70°F) and a BOD reduction of 70% during the winter (mean air temperature 30°F) from a pulp and paper mill waste with a flow of 30 mgd. The waste has an average temperature of 100°F and an initial BOD of 360 mg/l. The BOD removal characteristics at 20°C are defined by the relationship:

$$\frac{L_o}{L} = kt + 1$$

in which k has the value 0.5 at 20°C. The temperature effect on k is defined:

$$k_t = k_{20^o} \ 1.085^{(t-20)}$$

1 Volume of basin

a Summer conditions

The temperature of the basin contents is defined by a rearrangement of equation 3b.

$$D/T = 1.6 \frac{(T_a - T_w)}{(T_w - T_i)}$$

A trial and error solution is necessary. As a first assumption let $T_w = 86^oF$ (30°C). The BOD removal coefficient is therefore:

$$k_{30^oC} = 0.5 \ (1.085)^{10} = 1.13$$

The required detention period is therefore:

$$\frac{360}{72} = 1.13t + 1$$

$$t = 3.5 \text{ days}$$

Using a depth of 8 ft:

$$D/T = 2.26$$

T_w = 88°F which is close to the assumed 30°C

b Winter conditions

Assuming the same retention period

$$T_w = 70^oF$$

$$kt = 0.53$$

Solving for required retention period

$$\frac{360}{180} = 0.53t + 1$$

$$t = 4.4 \text{ days}$$

$\therefore$ winter requirement controls

$$V = 3.0 \cdot 4.4 = 13.2 \text{ mg} = 1.76 \text{ mcf}$$

If the same area is maintained the depth must be increased to

$$\frac{1.76}{0.18} = 9.8 \text{ ft. use 10 ft.}$$

(alternately a new area and T_w is computed and K and V readjusted).

2 Aeration system

lbs O_2/day

= 1.3 lbs BOD removed/day

= (1.3) (360 ppm · 3 mgd · 8.34 · 0.80)

= 9350 ppd = 390 pph

a Surface aeration

assume $\frac{du}{dy} = 1/\text{sec}$

Maintain 1.5 ppm dissolved oxygen in basin

∴ lbs O_2/hr/mft^2 $= 300 \times \frac{7.5}{9.0} = 250$

For a surface area of 180,000 ft^2

lbs O_2/hr = 250 · 0.18

= 45

∴ lbs O_2/hr from mechanical aerators = 390 = 45 = 345

b Mechanical aeration

Use a mechanical aerator designed to transfer 3.5 lbs O_2/hp-hr (gross power) at 20°C zero dissolved oxygen in water. The oxygen transfer rate in waste ($\alpha = 0.90$ at 25°C and 1.5 ppm DO is:

$$N = N_o \frac{C_{sw} - C_L}{C_s} \cdot 1.02^{(t-20)}$$

$$N = 3.5 \cdot \frac{7.8 - 1.5}{9.02} \cdot 1.02^{(5)} \cdot 0.90$$

= 2.5 lbs O_2/hp - hr

Using 4 aeration units per basin, each unit must transfer

345/8 = 43 lbs. O_2hr

The required horsepower per unit is

$$\frac{43}{2.5} = 17$$

∴ use 8 - 20 hp surface aeration units

3 Nutrient addition

Basis 4.1 lbs N/100 lbs BOD removed

0.6 lbs P/100 lbs BOD removed

lbs BOD removed/day = 7,200

lbs N/day = 72 · 4.1 = 295

lbs P/day = 72 · 0.6 = 43

TRICKLING FILTERS

BOD removal is related to:

1 hydraulic loading

2 filter depth

3 film surface area

4 temperature

5 organic removal characteristics

6 recirculation

A Hydraulic Loading

Time of contact function of hydraulic loading

$$t = C{A_v}^m D/Q^n \qquad (1)$$

in which Q = hydraulic loading

D = filter depth

A_v = specific surface

BOD removal

$$L/L_o = CQ^n \qquad (2)$$

B Depth

$$Le/Lo = e^{-KD} \qquad (3)$$

for constant hydraulic loading and specific surface

The quantity of biological film per unit area is:

$$S_t = CA_v \qquad (4)$$

Combining equations (1) and (4) and assuming first order kinetics yields:

$$L/Lo = e^{-kscAv^{(1+m)}} D/Q^n \qquad (5)$$

(See Figure 7)

C Filter film surface - removal increases with increasing surface area/ft^3.

D Temperature - removal increases with increasing temperature; decrease in removal with temperatures in excess of 35°C.

E Organic Removal Characteristics

Retardant reaction with some wastes.

Removal equation modified to form:

$$\frac{Le}{Lo} = \frac{1}{1 + \text{[illegible]}D^m/Q^n} \qquad (6)$$

F Recirculation - effective when exponent is less than 0.67; using equations (5) or (6) in which

$$lo = \frac{la + Nle}{1 + N} \qquad (7)$$

N = recirculation ratio.

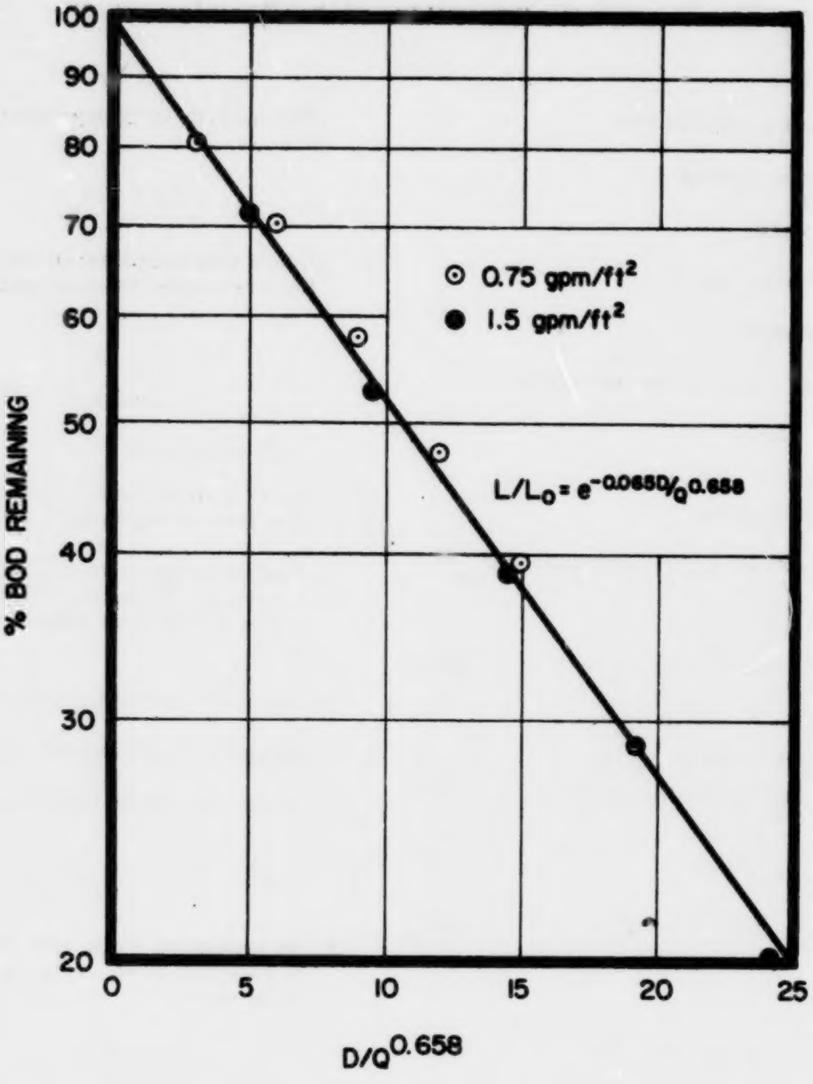


Figure 7

HIGH RATE BIOLOGICAL FILTRATION CORRELATION FOR DILUTE BLACK LIQUOR

NOMENCLATURE

a = fraction of BODs removed converted to sludge

a^1 = fraction of BODs removed oxidized

b = average endogenous rate, 1/day

I = inert suspended solids in waste

K_2 = BOD removal rate constant, 1/hrs.

Lr = BOD removed, mg/l

Lo = BOD after mixing with recycle, mg/l

Le = BOD of effluent, mg/l

n = exponent

Sa = average mixed liquor suspended solids, mg/l

So = initial mixed liquor suspended solids, mg/l

K_{La} = oxygen transfer rate coefficient

C_s = oxygen saturation in water

C_L = dissolved oxygen concentration

T = temperature

G_s = air flow, scfm

h = depth, ft.

p = aerator spacing correction

R = rotor speed, ft/sec.

D = diameter, ft.

N = oxygen transfer rate, mass/unit time

N_o = oxygen transfer rate, mass/unit under standard conditions, zero DO, 20°C

r = recirculation ratio, Q/R

r_r = oxygen uptake rate, mg/l/hr

x = oxygen transfer ratio, K_{La} waste/K_{La} water

Q = flow

t = time

This outline was prepared by W. W. Eckenfelder, Professor of Sanitary Engineering, Department of Civil Engineering, University of Texas, Austin, TX 78712.

THE BASIS FOR CHLORINATION OF WASTEWATERS

I INTRODUCTION

A In a recent survey of all municipal sewage treatment plants, it was reported that an overall 30% of treatment plants were provided with facilities for introduction of chlorine in connection with treatment plant operations.

Briefly, the survey of treatment plants utilizing chlorine may be summarized as follows:

Population served	Total number of plants	Plants with chlorination	Percentage with chlorination
less than 1,000	2,130	392	18
1,000 to 5,000	3,468	921	27
5,000 to 10,000	863	340	39
10,000 to 25,000	595	292	49
25,000 to 50,000	199	127	64
50,000 to 100,000	99	54	55
More than 100,000	164	90	61

B In reviewing publications relating to the use of chlorine with relation to wastewaters, the uninitiated worker quickly can gain an impression that chlorine is used in wastewater treatment operations as an almost-universal panacea, as a means of solving whatever problems seem to be plaguing the operations of the particular plant at the time.

C The purpose of this discussion is to review the common applications of chlorine to wastewaters and in the treatment of wastewaters, with special reference to the forms of chlorine that may be applied, places where chlorine may be applied, and the purposes or consequences of chlorination of wastewaters.

II USEFUL PROPERTIES OF CHLORINE

In terms of its significance in wastewater treatment processes, the important properties of chlorine include the following:

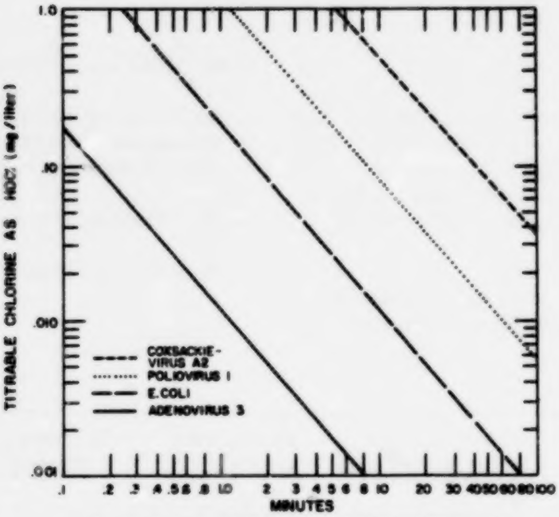
A Chlorine is a powerful oxidizing agent.

B Chlorine is poisonous to living organisms.

1 The poisonous properties of chlorine probably are exerted through its oxidizing ability, through which enzyme systems essential to life are irreversibly oxidized, or at least are inactivated.

2 According to the category of organisms for which chlorine is being used as a poison, chlorine could be called a germicide, a bactericide, a disinfecting agent, an algicide, an ovocide, a cysticide, or by any of several other "-cide" terms.

3 Different categories of organisms differ widely in their susceptibility to chlorine. Figure 1 illustrates the relative susceptibility of Escherichia coli and three



RELATIONSHIP BETWEEN CONCENTRATION AND TIME FOR 99% DESTRUCTION OF E.COLI AND 3 VIRUSES BY HYPOCHLOROUS ACID (HOCl) AT 0-6° C.

FROM: BUTTERFIELD, C.T.; WATTIE, E.; MEGREGIAN, S.; & CHAMBERS, C.W.;[illegible] CLARKE, N.A. & KABLER, P.W.;[illegible] CLARKE, N.A.; STEVENSON, R.E., & KABLER, P.W.[illegible] AND WEIDENKOPF, S.J.[17] COMPOSITED FROM DATA AND FIGURES

Figure 1

different kinds of viruses, to hypochlorous acid.

4 The rate at which the disinfecting (killing) process takes place is variable, and subject to control through management of such interrelated factors as temperature, concentration, pH, and the amount, kind, and physical state of other suspended and dissolved substances present in the water.

C Chlorine is highly soluble in water, and can be introduced economically into water and wastewater with accuracy and with adequate provision to protect the health and safety of operational personnel and the population which will be exposed to contact with the chlorine-treated waters.

IV USEFUL FORMS OF CHLORINE

A Most commonly, chlorine is added to to water in solution, being kept in tanks in liquid form under pressure; the liquid chlorine is converted to gas which in turn is dissolved into the water or wastewater being treated.

B Elemental chlorine, Cl_2, in the concentrations applied is quickly converted into other forms, characterized by the following examples:

1 Hydrolysis occurs:

$$Cl_2 + H_2O \longrightarrow HOCl + H^+ + Cl^-$$

2 Ionization of the hypochlorous acid occurs with increasing pH:

$$HOCl \rightleftharpoons H^+ + OCl^-$$

At pH 5 and lower, practically all the chlorine is in the form of hypochlorous acid; at higher pH levels, increasing ionization occurs until practically all the chlorine is in the form of the hypochlorite ion at pH 9. Hypochlorous acid is a far more active chemically than the hypochlorite ion.

C Chlorine also may be added in the form of sodium or calcium hypochlorite, as chloramine, or as chlorine dioxide.

1 Hypochlorite ions enter into the same sort of equilibrium reaction in water as indicated above:

$$Ca(OCl)_2 \text{ —— } Ca^{++} + 2OCl^-$$

$$H^+ + OCl^- \rightleftharpoons HOCl$$

2 Chlorine dioxide is a gas, and is extremely active chemically and as a germicide.

3 Chloramines are formed in water containing ammonia; when chlorine is added, a mixture of monochloramine (NH_2Cl), and dichloramine ($NHCl_2$), are formed.

If enough chlorine is added to react with all the available NH_3 and still leave an excess of chlorine, then nitrogen trichloride (NCl_3) may be formed. Chloramines are less reactive chemically and less effective as germicides, than are the free forms of chlorine.

V REASONS FOR APPLYING CHLORINE TO WASTEWATERS

A Odor Control

1 If sewage becomes anaerobic, whether in the collecting system of sewers, in any unit of a wastewater treatment plant, or in a long outfall line, then unpleasant odors may be developed. These odors are due to the formation of such foul-smelling substances as hydrogen sulfide, indole, skatole, mercaptans, and cadaverin.

Hydrogen sulfide usually is regarded as the forerunner of the other foul-odor substances. Accordingly, odor-control measures are quite likely to result in control of unpleasant odors from all the substances listed.

2 Role of chlorine. Chlorine, when applied, reacts with H_2S, thus:

$$Cl_2 + H_2S \longrightarrow 2\,HCl + S$$

In addition, the addition of chlorine results in a slowing of biological activity, thereby reducing the rate at which oxygen is removed from the sewage.

3 Mode of application

a Any of the forms of chlorine indicated above may be added to sewage for odor control. However, since chlorine also reacts indiscriminately with other materials present, some workers prefer to add ferrous chloride for a more selective removal of H_2S, thus:

$$H_2S + FeCl_2 \longrightarrow FeS + 2\,HCl$$

Chlorinated benzols also have been applied in sewer systems for odor control.

b To control odors in sewer lines, chlorine is added as far up-sewer from the treatment plant as possible.

4 Chlorine treatment is highly regarded for odor control. In the concentrations used (usually 4 - 5 mg/liter, and sometimes over as wide a range as 3 - 30 mg/liter), a residual chlorine should not be produced, and treatment processes should not be impaired.

B Corrosion Control

1 Besides being an important contributor to unpleasant odors, H_2S formation can result in damage to concrete, mortar, and iron pipes. H_2S, when oxidized, results in production of sulfuric acid. Therefore, any measures taken to prevent formation of H_2S also contribute to corrosion control.

2 Dosages sufficient to prevent formation of H_2S, as above, are indicated.

C Control of Operational Problems

1 Types of operational problems

a Ponding, on trickling filters, sometimes results from formation of surface growths of organisms. These organisms partially or completely occlude the passageways for sewage through the trickling filters.

b Bulking, or failure of satisfactory settling of activated sludge, sometimes results when filamentous organisms, such as Sphaerotilus natans, and possibly other kinds of organisms, become quite prominant in the biota of activated sludge systems.

c Foaming sometimes occurs in Imhoff tanks.

d Septic, or anaerobic. conditions in various parts of a treatment plant may occur when the rate of flow or holding time in tanks or conduits is excessive and where reaeration is not provided.

2 The application of chlorine often is a useful and practical means of solving the above types of problems. The principle of chlorine application is to add a limited amount of chlorine, sufficient to inactivate or kill (selectively) the troublesome organisms, but not to sterilize the unit. In this respect, it is pointed out that there is a protection to the organisms most important in sewage treatment due to (a) the tremendous numbers of organisms present, (b) inherently greater resistance of the treatment organisms than the nuisance organisms to chlorination (debatable), and (c) treatment organisms usually are deeply embedded in a slime matrix or activated floc, and thereby are somewhat less accessible to chlorine than other forms.

D Disinfection of Sewage Effluents

1 Sewage is known to contain tremendous numbers of microorganisms of intestinal origin. When individuals harboring pathogenic organisms, whether bacteria, viruses, protozoa, and other forms of disease-causing organisms, will be present. Such organisms, when present, constitute a hazard to the health and safety of individuals coming into contact with such sewage or treatment plant effluents unless measures are taken to destroy such organisms.

a In recent years, an epidemic of infectious hepatitis was traced to shellfish harvested from polluted waters in Raritan Bay. A pollution study of some magnitude was initiated, and considerable numbers of bacteria attributable to waste treatment plants adjoining Raritan Bay were demonstrated in the study. During the period when wastewater treatment plants chlorinated the treatment plant effluents, enteric pathogenic bacteria could not be recovered. However, when chlorination of treatment plant effluents was discontinued, *Salmonella* were discovered with some regularity at sampling points related to the above waste treatment plant discharges.

b In studies of the Red River of the North, *Salmonella* has been discovered with great regularity in waters polluted through discharge of inadequately treated wastewaters. In some cases, *Salmonella* has been discovered where the fecal coliform count was only a few hundreds per 100 ml.

2 Chlorine functions as a disinfectant in the sense that it is applied in dosages considered sufficient to destroy the pathogenic (disease-causing) organisms. Disinfection is not construed to mean total destruction of all living organisms present in the sewage effluents (sterilization).

3 For disinfection, chlorine must be added in sufficient concentration, and with a sufficient contact time, to ensure destruction of the pathogenic bacteria.

a One basis of chlorine application for disinfection, widely noted in textbooks of sanitary engineering practices, provides recommendations for adequate disinfection by adding chlorine in an amount sufficient to kill 99.9% of all coliform bacteria in the sewage, or sewage effluent, after a contact time of 15 minutes, and to have a chlorine residual of 0.5 mg/liter (according to one recommendation, the residual chlorine should be 2 mg/liter). A widely-quoted table of chlorine application follows:

Table: Amounts of chlorine required for disinfection of sewage and sewage effluents, with chlorine residual 0.5 mg/liter after contact time of 15 minutes.

Type of Sewage or Effluent	Probable Chlorine Requirements		Chlorinator Capacities*	
	mg/liter	lb/day/1000 persons	mg/liter	lb/day/1000 persons
Raw sewage, depending on strength and staleness	6 - 25	5 - 21	30	25
Settled sewage	5 - 20	4 - 17	25	20
Chemically precipitated sewage	3 - 20	3 - 17	25	20
Trickling filter effluent	3 - 20	3 - 17	25	20
Activated sludge effluent	2 - 20	2 - 17	25	20
Intermittent sand filter effluent	1 - 10	1 - 3	15	12

*For sewage flow of 100 gallons per capita per day.

b It is known that the time-concentration-temperature relationship of disinfection can be formulated in a manner analogous to demonstration of the progressive exertion of the biochemical oxygen demand. Accordingly, there has been some interest in determining amounts of chlorine to be added, based on the bacterial results to be achieved in the receiving water at some point downstream from the discharge of the treatment plant effluent.

c The attached figure, based on chlorine requirements for potability treatment of clear water, with a 30 minute contact time, are quite at variance with the requirements for producing a relatively safe effluent from a wastewater treatment plant.

E Reduction of BOD

1 It is emphasized that the action of chlorine is indiscriminate when introduced into wastewaters and treatment plant effluents. Chlorine simultaneously is killing or inactivating living organisms with which it comes into contact in sufficient concentration, for a sufficient time, and it reacts with inanimate inorganic and organic matter which also is present.

In reacting with organic material, chlorine has been stated to reduce from 10% to 35% of BOD when sufficient chlorine has been added to provide a residual after 15 minutes of contact time.

2 In reducing BOD through chlorination, the action has been attributed to

a Outright chemical oxidation of the organic material,

b Combination of chlorine with organic matter to form inherently toxic compounds (such as organic chloramines), and

c Reaction of chlorine with organic matter to form chlorinated compounds which are biologically oxidized more slowly than their predecessors.

3 Chlorination of sewage for the purpose of reducing BOD is not a recommended practice, except possibly in emergencies, pending installation of adequate treatment. The principal need for chlorination for BOD reduction is to delay (and hopefully, to diffuse) the oxygen-depleting material in the receiving water to an extent such that anaerobic conditions will not develop in the aquatic environment.

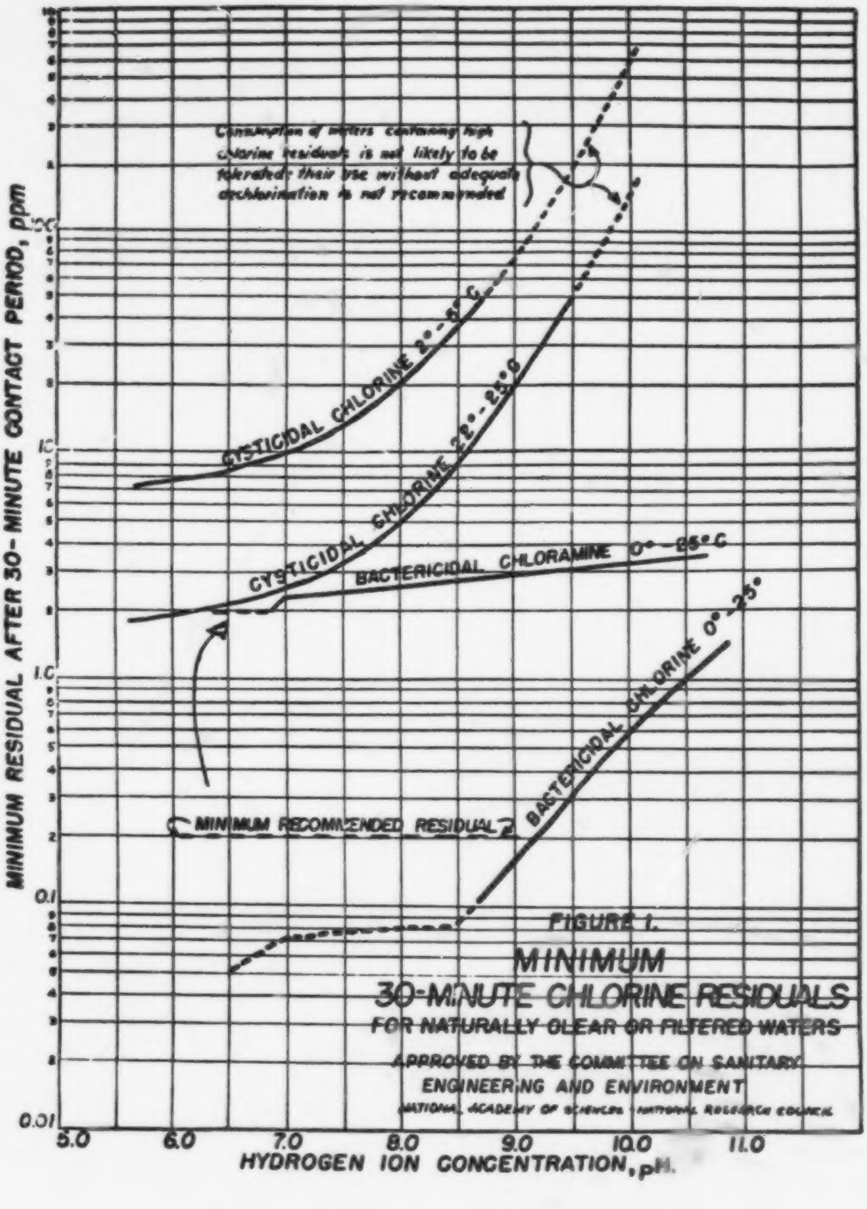


FIGURE 1.

MINIMUM
30-MINUTE CHLORINE RESIDUALS
FOR NATURALLY CLEAR OR FILTERED WATERS

APPROVED BY THE COMMITTEE ON SANITARY
ENGINEERING AND ENVIRONMENT
NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL

REFERENCES

1 The Federation of Sewage and Industrial Wastes Association. Sewage Treatment Plant Design. 1959.

2 Great-Lakes-Upper Mississippi River Board of Sanitary Engineers. Recommended Standards for Sewage Works. 1960.

3 Cosens, Kenneth W. The Operation of Sewage Treatment Plants. A reprint from Public Works Magazine.

4 Imhoff and Fair. Sewage Treatment. 1956, Book.

This outline was prepared by H. L. Jeter, Director, National Training Center, FWQA, Cincinnati, OH 45226.

CHLORINE DETERMINATIONS AND THEIR INTERPRETATION

I INTRODUCTION

Chlorine normally is applied to water as a bactericidal agent; it reacts with water contaminants to form a variety of products containing chlorine. The difference among applied and residual chlorine represents the chlorine demand of the water under conditions specified. Wastewater chlorination is particularly difficult because the concentration of organisms and components susceptible to interaction with chlorine are high and variable. Interferences with the chlorine determination in wastewater confuse interpretation with respect to the chlorine residual at a given time and condition, its bactericidal potency, or the future behavior.

II CHEMISTRY OF CHLORINATION

A Chlorine compounds (Cl_2) dissolve in water, and hydrolyze immediately according to the reaction.

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^-$$

The products of this reaction are hypochlorous and hydrochloric acid. The reaction is reversible, but at pH values above 3.0 and concentrations of chlorine below 1000 mg/l the shift is predominantly to the right leading to hypochlorous acid (HOCl).

Hypochlorous acid is a weak acid and consequently ionizes in water according to the equation:

$$HOCl \rightleftharpoons H^+ + OCl^-$$

This reaction is reversible. At a pH value of 5.0 or below almost all of the chlorine is present as hypochlorous acid (HOCl) whereas above pH 10.0 nearly all of it exists as hypochlorite ion (OCl^-). The pH value that will control is the pH value reached after the addition of chlorine. Chlorine addition tends to lower the pH and the addition of alkali hypochlorites tends to raise the pH.

B The initial reactions on adding chlorine to wastewaters may be assumed to be fundamentally the same as when chlorine is added to water except for the additional complications due to contaminants and their concentration.

Hypochlorous acid (HOCl) reacts with ammonia and with many other complex derivatives of ammonia to produce compounds known as chloramines. Formation of the simple ammonia chloramines includes:

1 $NH_3 + HOCl \rightarrow \underset{\text{monochloramine}}{NH_2Cl} + H_2O$

2 $NH_2Cl + HOCl \rightarrow \underset{\text{dichloramine}}{NHCl_2} + H_2O$

3 $NH_2Cl + NHCl_2 \rightarrow N_2 + 3\ HCl$

The distribution of the ammonia chloramines is dependent on pH, as illustrated below:

	Percentage of Chlorine Present as	
pH	Monochloramine	Dichloramine
5	16	84
6	38	62
7	65	35
8	85	15
9	94	6

The formation of the ammonia chloramines are dependent on pH, temperature, and chlorine-ammonia ratio. Chlorine reactions with amino acids are likely; product disinfecting powers are lower than those of chlorine or of ammonia chloramines.

III TERMINOLOGY

A Terms used with Respect to Application Site

1 Pre-chlorination - chlorine added prior to any other treatment.

2 Post-chlorination - chlorine added after other treatment.

3 Split chlorination - chlorine added at different points in the plant - may include pre- and post-chlorination.

B Terms used in Designating Chlorine Fractions

1 Free available residual chlorine - the residual chlorine present as hypochlorous acid and hypochlorite ion.

2 Combined available residual chlorine - the residual chlorine present as chloramines and organic chlorine containing compounds.

3 Total available residual chlorine - the free available residual chlorine + the combined available residual chlorine - may represent total amount of chlorine residual present without regard to type.

In ordinary usage these terms are shortened to free residual chlorine, combined residual chlorine and total residual chlorine. In the chlorination of wastewaters only combined residual chlorine is ordinarily present and is often improperly termed chlorine residual.

C Breakpoint chlorination specifically refers to the ammonia-chlorine reaction where applied chlorine hydrolyzes and reacts to form chloramines and HCl with the chloramines eventually forming N_2 + HCl as in I. B. 3. Assuming no other chlorine demand, the total chlorine residual will rise, decrease to zero and rise again with increasing increments of applied chlorine. Other substances may produce humps in the applied chlorine vs residual chlorine plot due to oxidation of materials other than ammonia. Sometimes these are erroneously considered as a breakpoint.

IV ANALYTICAL METHODS

The o-Tolidine color test and Iodometric titration methods are the basis for numerous modifications for determining chlorine residuals in water. The relative advantages of a specific determination depends upon the form in which the reactable chlorine exists and the amount and nature of interferences in the water.

Iodometric titration using the amperometric endpoint appears to be the most accurate residual chlorine method available (Standard Methods APHA 12th Ed., p. 375, and ASTM Standards, Part 23). The o-Tolidine and o-Tolidine Arsenite methods require little apparatus, and are readily adapted as a field or control test. The Starch Iodine color titration endpoint for iodometric titration is suitable for use on clean water or stock solutions and may be useful on certain types of wastewater residuals. Selection of a suitable method of determining chlorine residuals depends upon the correlation of the determined residual and the bacterial kill in the presence of existing interferences under applied conditions.

A Iodometric Method

1 Scope and application

This method is applicable to the determination of total chlorine residual in wastewaters, polluted waters and some industrial wastewaters.

2 Summary of method

When a sample is treated with a measured excess of standard phenylarseneoxide solution, or a standard thiosulfate solution, followed by the addition of iodide, the iodine liberated at the proper pH is stoichiometrically proportional to the total chlorine present. The liberated iodine reacts with the phenylarseneoxide or thiosulfate before any is lost to other extraneous reactions. The excess phenylarseneoxide or thiosulfate is titrated with standard iodine solution in the presence of starch until the phenylarseneoxide or thiosulfate is completely oxidized. The end-point of the tiration is the next addition of standard iodine solution that causes a faint blue color to persist in the sample.

3 Interferences

a Organic matter - reacts with liberated iodine.

b Manganic manganese - liberates iodine from iodide at pH 4.0.

c Ferric iron, ferricyanide and nitrites up to 100 mg/l do not interfere at a pH of 4.0.

d Chromates - reduce phenylarseneoxide or thiosulfate to an appreciable extent before the excess can be titrated with standard iodine.

e Excessive color and turbidity

B Iodometric Method with Amperometric End-Point

1 Scope and application

This method is applicable to the determination of total chlorine residual in wastewaters, polluted waters and some industrial wastewaters. The back-titration method is essential for wastewaters in contrast to the direct titration with phenylarseneoxide in clean waters.

2 Summary of method

When a sample is treated with a measured excess of standard phenylarseneoxide solution followed by the addition of iodide, the iodine liberated at the proper pH is stoichiometrically proportional to the total chlorine present. The iodine liberated reacts with the phenylarseneoxide before any is lost to other extraneous reactions. When the cell is immersed in a sample so treated, no current is generated due to halogens nor is any further current generated, as the excess phenylarseneoxide is titrated with standard iodine solution until the phenylarseneoxide is completely oxidized. The end-point of the titration is the next addition of standard iodine solution that causes further current to be generated and a microammeter response or pointer deflection.

NOTE: As the end-point is approached each increment of standard iodine solution causes a temporary deflection of the microammeter, but the pointer drops back to about its original position. The true end-point is reached when a small addition of standard iodine solution gives a definite and permanent pointer deflection.

3 Interferences

a Organic matter - reacts with the liberated iodine.

b Manganic manganese - liberates iodine from iodide at a pH of 4.0.

c Ferric iron, ferricyanide and nitrites up to 100 mg/l do not interfere at a pH of 4.0.

d Chromates - reduces phenylarseneoxide to an appreciable extent before the excess can be titrated with standard iodine solution.

e Cupric ions may cause erratic behavior of the apparatus.

f Cuprous and silver ions tend to poison the electrode.

C Orthotolidine Method

1 Scope and application

This method is applicable to the determination of total chlorine residual in wastewaters, polluted waters and some industrial wastewaters.

2 Summary of method

When a sample is treated with a measured amount of orthotolidine reagent, the orthotolidine is oxidized in the resulting acid solution by chlorine and chloramines and other oxidizing agents to produce a yellow-colored compound (Holoquinone). The color produced at pH values of less than 1.8 is proportional to the amount of chlorine present and is suitable for quantitative measurement. The chlorine residual in mg/l is read directly from the colored glass disks or sealed colored liquid standards or is calculated from a previously prepared standard curve. NOTE: Particular attention is called to the importance of warming the sample to 20°C after the addition of orthotolidine reagent in order to complete the reaction.

3 Interferences

a Organic matter - oxidizes orthotolidine to produce a yellow color (Holoquinone).

b Manganic manganese - in concentrations above 0.01 mg/l oxidizes orthotolidine to produce a yellow color (Holoquinone).

c Ferric iron - in concentrations above 0.3 mg/l oxidizes orthotolidine to produce a yellow color (Holoquinone).

d Nitrites - in concentrations above 0.10 mg/l of nitrite nitrogen oxidizes orthotolidine to produce a yellow color (Holoquinone).

e Excessive color and turbidity.

D Orthotolidine- Arsenite Method

1 Scope and application

This method is applicable to the determination of free residue chlorine and combined residual chlorine in wastewaters, polluted waters and industrial wastewaters, but as normally carried out for wastewaters, etc. total residual chlorine is measured.

2 Summary of method

A sample is split into two fractions (a) and (b). Sample (a) is treated with a measured amount of arsenite reagent, followed by the addition of orthotolidine reagent. The arsenite reacts with chlorine while orthotolidine reacts with ferric iron, manganic manganese and nitrite nitrogen to produce additional color (represents interfering color). Sample (b) is treated with a measured amount of orthotolidine reagent. The orthotolidine is oxidized in the resulting acid solution by chlorine, chloramines and other oxidizing agents to produce a yellow-colored compound (Holoquinone) as described in the orthotolidine method (represents total amount of residual chlorine present and interfering color). Mg/l total residual chlorine = b - a if color compensation is not made directly. NOTE: more accurate readings may be obtained if cells containing sample fractions (a) and (b) are placed in the comparator in such relative positions that color compensation is made directly.

3 Interferences

a High color and turbidity

V INTERPRETATION

In general residual chlorine concentrations obtained by the iodometric titration method (starch iodide end-point and amperometric end-point) will be higher than the concentrations obtained from the orthotolidine and the orthotolidine-arsenite methods. Some of the reasons for the difference have been listed under the individual methods. Extensive studies have indicated that consistently better correlation between bacterial kill and chlorine residual found is possible when the titration method is used.

REFERENCES

1 Standard Methods for the Examination of Water and Wastewaters, 12th Ed., APHA, AWWA, WPCF. 1965.

2 1965 Book of ASTM Standards, Part 23 - Industrial Water; Atmospheric Analysis. American Society for Testing and Materials. Philadelphia, Pa.

3 Sawyer, C.N. Chemistry for Sanitary Engineers. McGraw-Hill Book Company, New York. 1960.

4 Moore, E.W. Fundamentals of Chlorination of Sewage and Wastes. Water and Sewage Works. Vol. 98, No. 3, March 1951.

5 Day, R.V., Horchler, D.H., and Marks, H.C. Residual Chlorine Methods and Disinfection of Sewage. Industrial and Engineering Chemistry, May 1953.

6 Marks, H.C., Joiner, R.R., and Strandskov, F.B. Amperometric Titration of Residual Chlorine in Sewage. Water and Sewage Works, May 1948.

This outline was prepared by J.L. Holdaway, Chemist, Technical Program, Middle Atlantic Region, FWQA, 918 Emmet Street, Charlottesville, VA 22901.

SECTION IV

TREATMENT METHODS FOR SMALL FLOWS

	Outline Number
Preliminary Engineering Report	18
Septic Tank - Soil Absorption Systems for Institutions, Recreational Areas, and Other Establishments	19
Small Treatment Systems (Package Plants)	20
Mechanical Systems for Tertiary Treatment	21
Sewage Lagoons	22
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Tertiary Treatment by Means of Lagoons and Land Irrigation Practices	22
Chlorination Practices	23

PRELIMINARY ENGINEERING REPORT

I ESSENTIAL TO DEVELOP BEST FACILITY

A Required by State Law

B Must be prepared by Licensed Engineer

II BASIC FUNCTION - DETERMINE PROBLEM AND FIND BEST SOLUTION

A Provide for Interim and Ultimate Collection, Treatment and Disposal of Wastes

B First Step is to gather all Pertinent Data

  1 Physical characteristics of area: topography, climatology, hydrology, soil characteristics, drainage basins, water location and quality, existing water and sewer service, zoning.

  2 Quantitative characteristics: population, history and trend; location and size of activities to be served, present and future; type of activity; activities to be protected; projection of future needs.

  3 Consider possibility of involving other entities; location and size of their facilities.

C Determine Quality and Quantity of Waste to be Treated

  1 Consider desirability of more than one plant

  2 Type of waste

  3 Location of waste load

  4 Accurate volume data essential

    a Measure waste flow

    b Measure water supply

    c Estimate per capita use

  5 Accurate waste strength data needed

    a Can be done by sampling

    b Can be done by estimation of type of use

D Type of Plant Depends on:

  1 Volume of waste

    a Basic load

    b Irregular use - Light, heavy or seasonal load

    c Storm water or infiltration

  2 Quality of waste

    a Domestic or special characteristics

    b Oil and/or grease

    c Toxic elements

E Degree of Treatment Needed

  1 Water quality standards have established this in many cases

  2 Water uses and volume of dilution available

    a Based on recreational activities in most cases

  3 Outfall line design essential to total plant

    a Serves as last element of treatment

    b Possibility of by-pass or malfunction

  4 Nutrients becoming more important factor

    a Evaluated with other sources

D Capability of Expansion

  1 How much, how soon?

  2 Is expansion possible?

  3 Is area available?

  4 Can higher treatment be provided in future if necessary?

E Operation

  1 How much is needed?

  2 If intermittent, can it be fitted into another job schedule?

  3 Technical requirements of operator

  4 Cost

F Other Factors

  1 Public acceptance

    a Pit privies or trees may do the job, but is it acceptable?

    b Location-away from business or residential locations or other class activities, as recreation.

G Finance

  1 How much will each cost initially?

  2 How much O & M cost?

  3 How much to expand?

III CONCLUSION AND RECOMMENDATION

A Should outline type, size and layout of best plant, all factors considered

  1 List alternatives considered and reasons for their rejection

  2 Local factors

  3 Good working relations with engineer

  4 Many meetings and exchange of ideas, data

This outline was prepared by E. W. Asselstine, Senior Engineer, State of Washington, Water Pollution Control Administration.

SEPTIC TANK - SOIL ABSORPTION SYSTEMS FOR INSTITUTIONS, RECREATIONAL AREAS, AND OTHER ESTABLISHMENTS

I INTRODUCTION

Septic tank and soil absorption systems are sometimes used for schools, parks, small institutions, and campgrounds where the quantities of sewage may be considerable.

Inasmuch as the usefulness of a septic tank system decreases as the sewage flow increases, competent sanitary engineering should be sought in the selection of treatment method and facility design.

An institutional septic tank system must include design features which adapt the treatment to specific needs and site conditions.

II ESTIMATING SEWAGE FLOW

A Water Meters

1 Provides average water use over time; thus it is necessary to estimate peak flow conditions for proper design.

2 Water used for irrigation or other purposes which will not enter the disposal system must be considered.

B Flow Measurements

1 In existing systems the actual sewage flow may be determined by direct measurement. In such cases, a measurement device providing a continuous recording showing variations in flow is recommended.

2 Consideration must be given to seasonal uses which may provide unusual flow rates.

C Empirical Estimates

1 Where it is impossible to obtain actual measurements, estimates of flow may be made using the number of persons to be served.

Table I is helpful in estimating flow. The figures given are averages and should be modified if local experience indicates significant variation from the average.

2 In systems where different waste sources may be diverted to separate systems, it may be necessary to determine the component flows. Table II provides an estimated distribution of sewage flows for typical wastes.

3 Flow may also be estimated by the number and type of plumbing fixtures installed. Table III shows one method used in estimating sewage flow from a park.

III FINDING SOIL ABSORPTION AREA

A Percolation Test

1 Should be representative of area

- a Six or more test holes spaced uniformly over proposed site
- b Test made at depth to be used for disposal field

2 Hole preparation

- a 4 to 12 inches in diameter
- b Vertical sides
- c Sides scratched to remove oil or other effects caused by auger which may affect test
- d Place coarse sand or fine gravel in bottom of hole
- e Fill hole with water over sufficient time period to permit swelling of soil particles and saturation of the soil

TABLE I - QUANTITIES OF SEWAGE FLOWS

Type of Establishment	Gallons Per Person Per Day (Unless Otherwise Noted)
Airports (per passenger)	5
Apartments--multiple family (per resident)	60
Bathhouses and swimming pools	10
Camps:	
Campground with central comfort stations	35
With flush toilets, no showers	25
Construction camps (semi-permanent)	50
Day camps (no meals served)	15
Resort camps (night and day) with limited plumbing	50
Luxury camps	100
Cottages and small dwellings with seasonal occupancy	50
Country clubs (per resident member)	100
Country clubs (per non-resident member present)	25
Dwellings:	
Boarding houses	50
additional for non-resident boarders	10
Luxury residences and estates	150
Multiple family dwellings (apartments)	60
Rooming houses	40
Single family dwellings	75
Factories (gallons per person, per shift, exclusive of industrial wastes)	35
Hospitals (per bed space)	250+
Hotels with private baths (2 persons per room)	60
Hotels without private baths	50
Institutions other than hospitals (per bed space)	125
Laundries, self-service (gallons per wash, i.e., per customer)	50
Mobile home parks (per space)	250
Motels with bath, toilet, and kitchen wastes (per bed space)	50
Motels (per bed space)	40
Picnic Parks (toilet wastes only) (per picknicker)	5
Picnic Parks with bathhouses, showers, and flush toilets	10
Restaurants (toilets and kitchen wastes per patron)	10
Restaurants (kitchen wastes per meal served)	3
Restaurants additional for bars and cocktail lounges	2
Schools:	
Boarding	100
Day, without gyms, cafeterias, or showers	15
Day, with gyms, cafeteria, and showers	25
Day, with cafeteria, but without gyms, or showers	20
Service stations (per vehicle served)	10
Swimming pools and bathhouses	10
Theaters:	
Movie (per auditorium seat)	5
Drive-in (per car space)	5
Travel trailer parks without individual water and sewer hook-ups (per space)	50
Travel trailer parks with individual water and sewer hook-ups (per space)	100
Workers:	
Construction (at semi-permanent camps)	50
Day, at schools and offices (per shift)	15

Table from Manual of Septic Tank Practice; DHEW-PHS

TABLE II - ESTIMATED DISTRIBUTION OF SEWAGE FLOWS, IN GALLONS PER DAY PER PERSON

Type of Waste	Volume, gallons per day per person				
Total Flow (gallons)	30	40	50	75	100
Kitchen wastes	0	7	10	10	15
Toilet wastes	15	15	20	25	30
Showers, washbasins, etc.	15	18	20	25	35
Laundry wastes	0	0	0	15	20

Example: In a household contributing 75 gallons of sewage per day per person, as shown in column 4, an average breakdown for each of the four types of wastes listed might be about 10 gallons per day per person for kitchen wastes; 25 gallons per day per person for toilet wastes; 25 gallons per day per person for shower wastes, bathtubs, and washbasins; and about 15 gallons per day per person for laundry wastes.

TABLE III - SEWAGE FLOW AT PUBLIC PARKS
(During hours when park is open)

Type of fixture	Gallons per hour per fixture	Type of fixture	Gallons per hour per fixture
Flush toilets	36	Showers	100
Urinals	10	Faucets	15

3 Fill hole with water and measure rate of water drop.

B Compute Size of Absorption Area

Table IV provides data on allowable rates of sewage effluent application to soil absorption areas.

TABLE IV - ALLOWABLE RATE OF SEWAGE APPLICATION TO A SOIL ABSORPTION SYSTEM

Percolation rate (time in minutes for water to fall 1 inch)	Maximum rate of sewage application (gallons per square foot per day)[1] for absorption trenches,[2] seepage beds, and seepage pits[3]	Percolation rate (time in minutes for water to fall 1 inch)	Maximum rate of sewage application (gallons per square foot per day)[1] for absorption trenches,[2] seepage beds, and seepage pits[3]
1 or less............	5.0	10.................	1.6
2....................	3.5	15.................	1.3
3....................	2.9	30[4]	0.9
4....................	2.5	45[4]	0.8
5....................	2.2	60[4] [5]	0.6

---

[1] Not including effluents from septic tanks that receive wastes from garbage grinders and automatic washing machines.

[2] Absorption area is figured as trench bottom area, and includes a statistical allowance for vertical sidewall area.

[3] Absorption area for seepage pits is effective sidewall area.

[4] Over 30 unsuitable for seepage pits.

[5] Over 60 unsuitable for absorption systems.

Example: Flow 5000 gpd; percolation rate, 1 inch in 5 minutes.

Absorption Trenches:

Standard trench, 2 feet width

5,000 gal/day ÷ 2.2 gal/sp. ft./day = 2,270 square feet of absorption area required.

2,270 ÷ 2 sq. ft./linear ft. = 1,135 feet of trench required.

Seepage Pits:

Seepage pit 10 foot diameter; depth of effective absorption area 25 feet; let d = effective depth of pit in feet; D equal pit diameter in feet. Effective sidewall area equals total area needed.

D(d) = 2,270 sq. ft.
3.14 (10) (d) - 2,270
Solve for d, effective depth of pit = 72 ft.
Obviously, more than one pit is required.
Design for 3 pits, 10 ft. in diameter.
72 ÷ 3 = 24 ft.
Use 3 pits, 10 ft. in diameter with an effective depth of 24 ft.

IV SEPTIC TANK DESIGN

A Functions of Septic Tank

1 Removal of solids

2 Sludge and scum storage

3 Biological treatment

4 Condition liquids for ground absorption

B Location--septic tank should be located such that contamination of any well, spring, or other source of water supply will be prevented.

C Compartment design

1 Single compartment (Figure 1) *(Same as Figure 15, page 33, Manual of Septic-Tank Practice).

a Pre-cast concrete tanks

b Steel fabricated tanks

c Concrete cast in-place tanks

d Access for checking and cleaning tanks

2 Two compartment tanks (Figure 2) *(Same as Figure 21, page 54, Manual of Septic-Tank Practice).

a Compartments separated by walls containing ports or ell fitting at proper elevation for liquid flow. Walls should also have gas vents to permit gas flow between compartments.

D Capacity--Capacity is one of the most important design considerations. Liberal tank capacity is advisable both for treatment efficiency and operational economy.

The net volume or effective capacity below the flowline of a septic tank, for flows up to 500 gallons per day, should be at least 750 gallons. For flows between 500 and 1,500 gallons per day, the capacity of the tank should be equal to at least $1\frac{1}{2}$ days' sewage flow. With flows greater than 1,500 gallons per day, the minimum effective tank capacity should equal 1,125 gallons plus 75 percent of the daily sewage flow; or

$$V = 1,125 + 0.75Q$$

where V is the net volume of the tank in gallons and Q is the daily sewage flow in gallons. If garbage grinders are used, additional volume for extra sludge storage may be desired to minimize the frequency of cleaning.

V DOSING TANKS

When the quantity of sewage exceeds the amount that can be disposed of in about 500 lineal feet of tile, a dosing tank should be used in conjunction with the septic tank, in order to obtain proper distribution of sewage throughout the disposal area and give the absorption bed a chance to rest or dry out between dosings. Rest periods are always advantageous, especially when the soil is dense. The dosing tank should be equipped with an automatic siphon which discharges the tank once every 3 or 4 hours. The tank should have a capacity equal to about 60 or 75 percent of the interior capacity of the tile to be dosed at one time.

Figure 4 - Septic tank and dosing tank with alternating siphons. *(Figure 23, page 57, Manual of Septic-Tank Practice).

In cases of large absorption fields (1000 feet or more) the use of alternating siphons, each discharging to half of the field, is suggested.

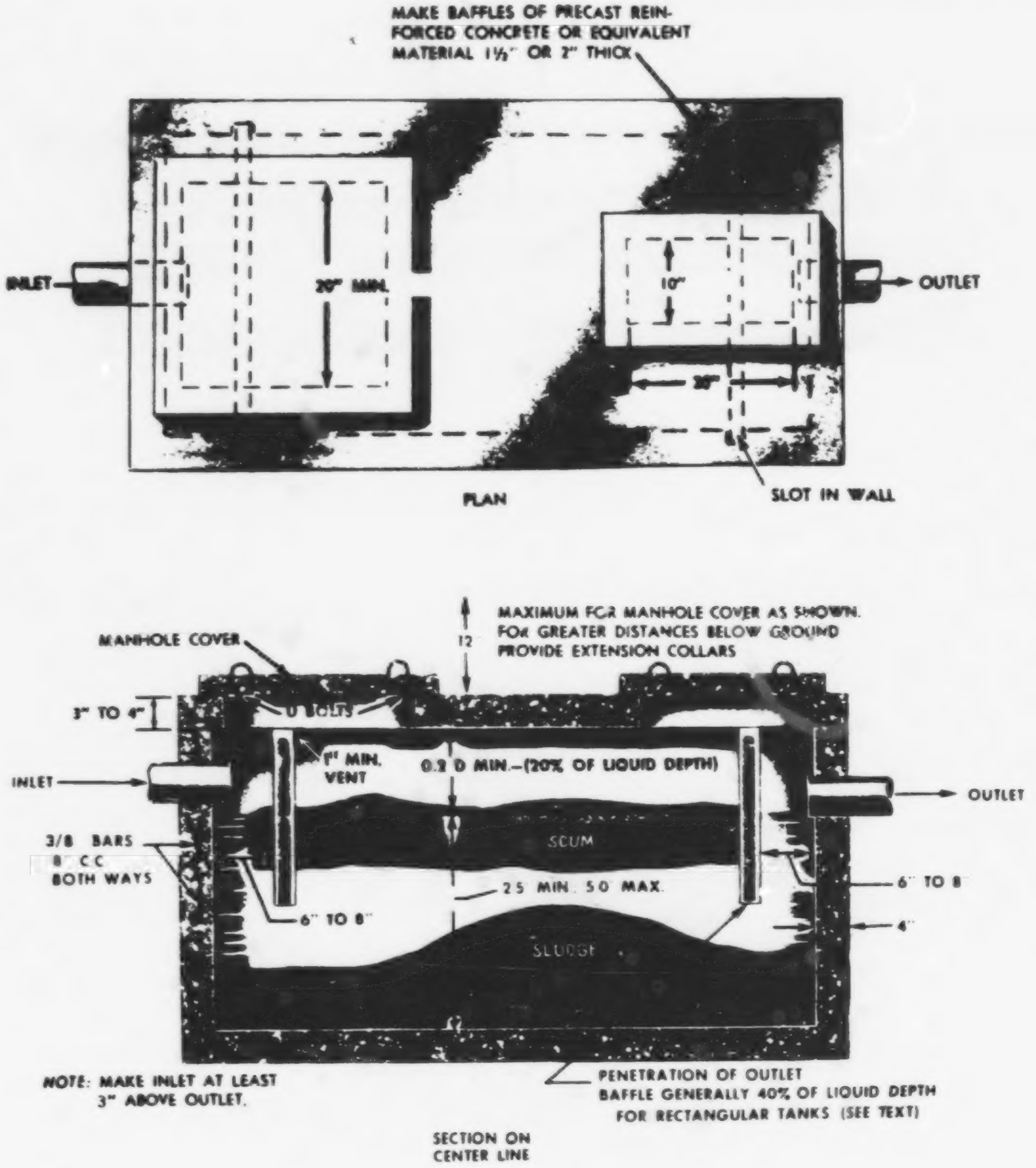

MAKE BAFFLES OF PRECAST REINFORCED CONCRETE OR EQUIVALENT MATERIAL 1½" OR 2" THICK
INLET
20" MIN.
10"
OUTLET
20"
PLAN
SLOT IN WALL
MAXIMUM FOR MANHOLE COVER AS SHOWN. FOR GREATER DISTANCES BELOW GROUND PROVIDE EXTENSION COLLARS
12
MANHOLE COVER
U BOLTS
3" TO 4"
1" MIN. VENT
0.2 D MIN.—(20% OF LIQUID DEPTH)
INLET
OUTLET
3/8 BARS 8" CC BOTH WAYS
SCUM
25 MIN. 50 MAX.
6" TO 8"
6" TO 8
4"
SLUDGE
NOTE: MAKE INLET AT LEAST 3" ABOVE OUTLET.
PENETRATION OF OUTLET BAFFLE GENERALLY 40% OF LIQUID DEPTH FOR RECTANGULAR TANKS (SEE TEXT)
SECTION ON CENTER LINE

Figure 1 .—Household septic tank.

Reproduced from best available copy.

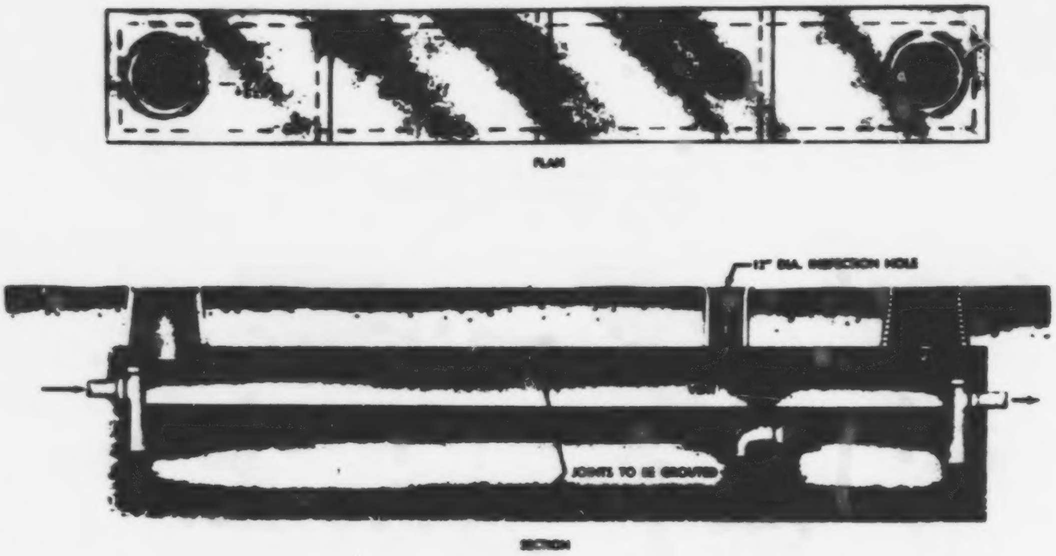

PLAN
12" DIA. INSPECTION HOLE
JOINTS TO BE GROUTED
SECTION

Figure 2 .—Battery of four precast reinforced-concrete septic-tank sections.

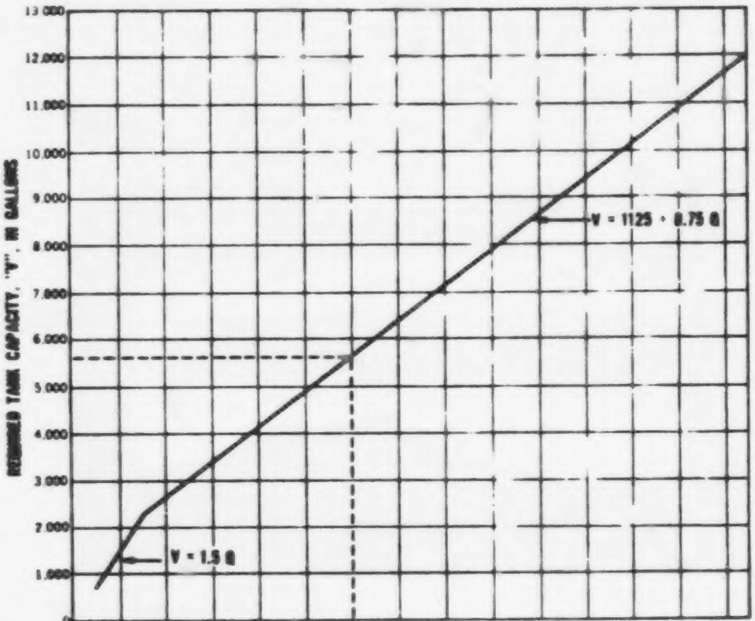


Figure 3 .—Septic-tank capacities for sewage flows up to 14,500 gallons per day.

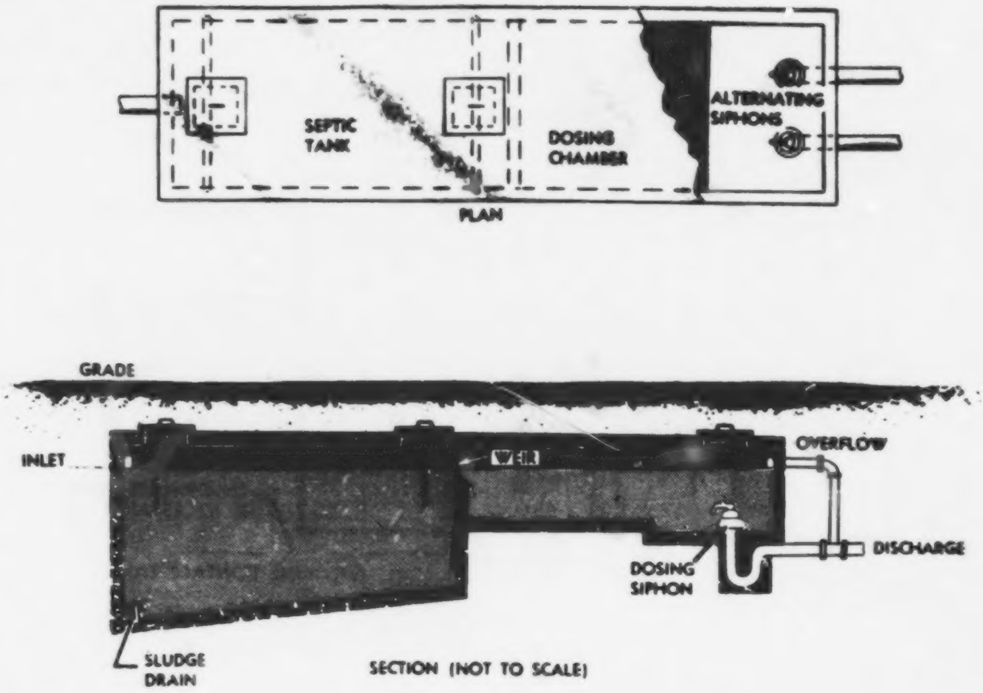

SEPTIC TANK
DOSING CHAMBER
ALTERNATING SIPHONS
PLAN
GRADE
INLET
WEIR
OVERFLOW
DISCHARGE
DOSING SIPHON
SLUDGE DRAIN
SECTION (NOT TO SCALE)

Figure 4.—Septic tank and dosing tank with alternating siphons.

VI SAND FILTER TRENCHES AND SAND FILTERS

When soil conditions are relatively impermeable, with percolation time exceeding 30 or 40 minutes per inch, filter trenches or subsurface sand filters may be necessary.

Figure 5 - Typical plan and section of a subsurface sand filter. *(Figure 27, page 63, Manual of Septic-Tank Practice).

Effluent collected in the under-drains of sand filter trenches and/or subsurface sand filters must be collected and chlorinated for disinfection before discharge to public waters.

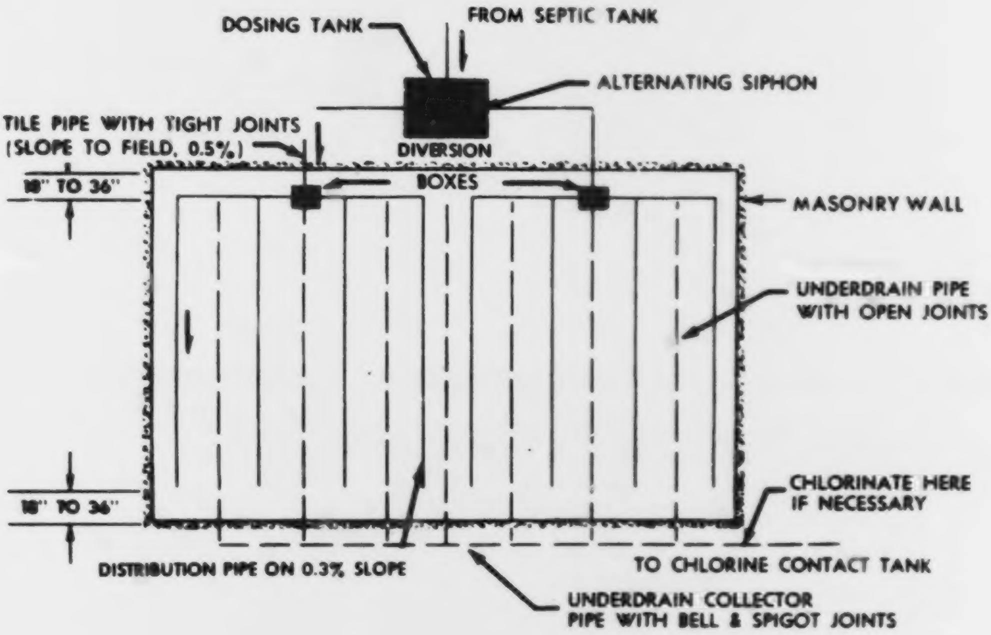
In cases where final disposal of the sewage effluents is to surface waters, a septic tank treatment system is usually inadequate and consideration should be given to more efficient treatment systems.

REFERENCE

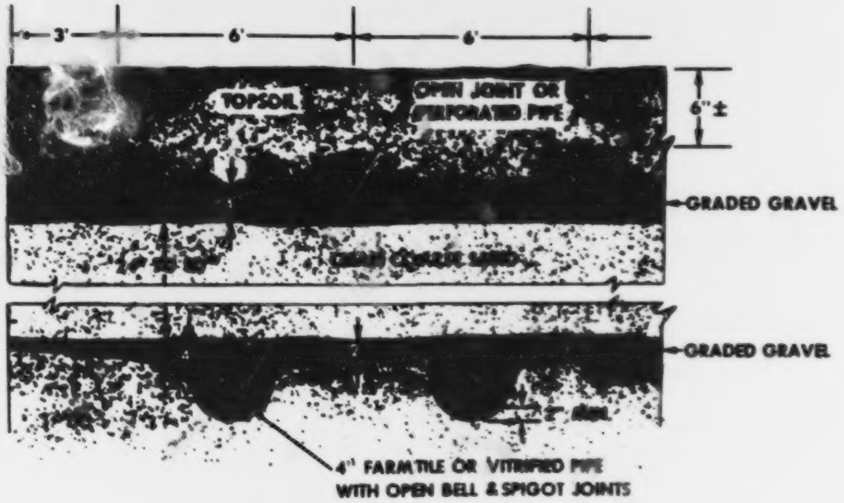
Manual of Septic-Tank Practice, USPHS-DHEW, Publication No. 526, Revised 1967.

This outline was prepared by Lyman J. Nielson, Sanitary Engineer, FWPCA Training Activities, PNWL.

*Figures may be found on indicated page of Manual of Septic-Tank Practice.


DOSING TANK
FROM SEPTIC TANK
ALTERNATING SIPHON
TILE PIPE WITH TIGHT JOINTS
(SLOPE TO FIELD, 0.5%)
DIVERSION
BOXES
18" TO 36"
MASONRY WALL
UNDERDRAIN PIPE
WITH OPEN JOINTS
CHLORINATE HERE
IF NECESSARY
18" TO 36"
DISTRIBUTION PIPE ON 0.3% SLOPE
TO CHLORINE CONTACT TANK
UNDERDRAIN COLLECTOR
PIPE WITH BELL & SPIGOT JOINTS

PLAN


3'
6'
6'
TOPSOIL
OPEN JOINT OR
PERFORATED PIPE
6"±
GRADED GRAVEL
24" TO 30"
CLEAN COARSE SAND
GRADED GRAVEL
2" MIN.
4" FARMTILE OR VITRIFIED PIPE
WITH OPEN BELL & SPIGOT JOINTS

SECTIONAL ELEVATION

Figure 5.—Typical plan and section of a subsurface sand filter.

Reproduced from
best available copy.

SMALL TREATMENT SYSTEMS
(PACKAGE PLANTS)

I DEFINITION

A Preassembled Units from Factory

B Sizes from 150, 000 gpd to Individual Homes

II TYPES (Figure 1)

A Complete-Mix Extended Aeration

B Contact Stabilization

C Trickling Filters

III MANUFACTURERS

A More than 20 Different Firms make Package Treatment Plant Units

B Extended Aeration Most Common

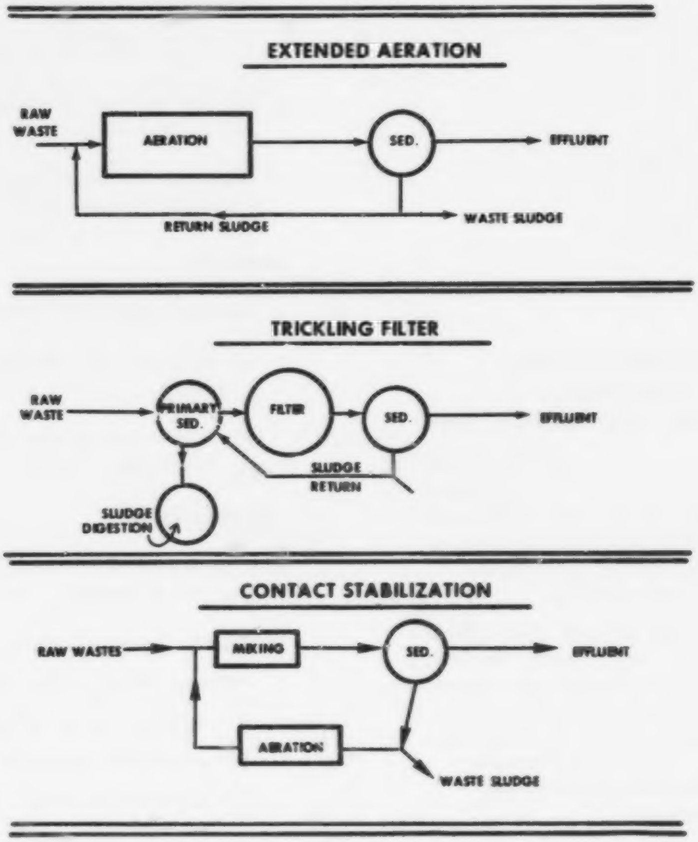
IV EXTENDED AERATION PLANTS

A Use

1 Survey in 1960 indicated 1224 plants in the states.

2 Most served schools, motels, industries, etc.

Figure 1

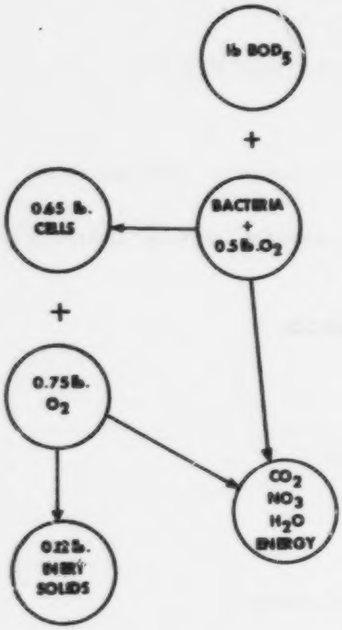

EXTENDED AERATION
RAW WASTE
AERATION
SED.
EFFLUENT
RETURN SLUDGE
WASTE SLUDGE
TRICKLING FILTER
RAW WASTE
PRIMARY SED.
FILTER
SED.
EFFLUENT
SLUDGE RETURN
SLUDGE DIGESTION
CONTACT STABILIZATION
RAW WASTES
MIXING
SED.
EFFLUENT
AERATION
WASTE SLUDGE

B Process Theory

1 Soluble BOD removal

a Organic matter is used by bacteria in new cell synthesis and basic metabolism. Figure 2 illustrates path of one pound of domestic sewage in a total oxidation system.

Figure 2



BOD REDUCTION
PATHWAY
COMPLETE OXIDATION SYSTEM

b Figure 3 illustrates the BOD removal curve and the rate of solids buildup with time and F/M ratios. The F/M ratio is the food to microorganism ratio or lb BOD_5/ lb MLVSS (mixed liquor volatile suspended solids).

NOTE: Solids go through three phases in their growth - log growth, declining growth and endogenous or auto oxidation. McKinney reports F/M ratios of 2.5 to 0.006 as defining range of declining growth phase. Extended aeration operates in declining growth and endogenous phases.

2 Solids accumulation

a Solids accumulate until system is in equilibrium or separate sludge wasting is employed. Otherwise, solids wasted from system as they are formed.

b Expressed by relation

$A = (aL_r - bMd) + Si - S$

A = accumulation of solids

a = fraction of food synthesized (approx. 0.65 for domestic sewage)

L_r = lb BOD_5 removed/day

b = fraction of solids oxidized/day

Md = mass of degradable solids in system

Si = inert solids entering system

S = lbs of solids wasted/day

c At equilibrium oxidation of 1 lb of BOD_5 results in 0.12 lb of inert solids

d Study at National Science Foundation indicated it took 36 to 49 days to build solids to desired level of 2500 mg/l. MLSS.

e Methods to lower startup time include

1) Seeding with sludge from another plant

2) Allow unit to operate as a primary plant for 1 week

3 Effluent BOD

a Composed of soluble portion and portion in solids

b Can be computed from relation

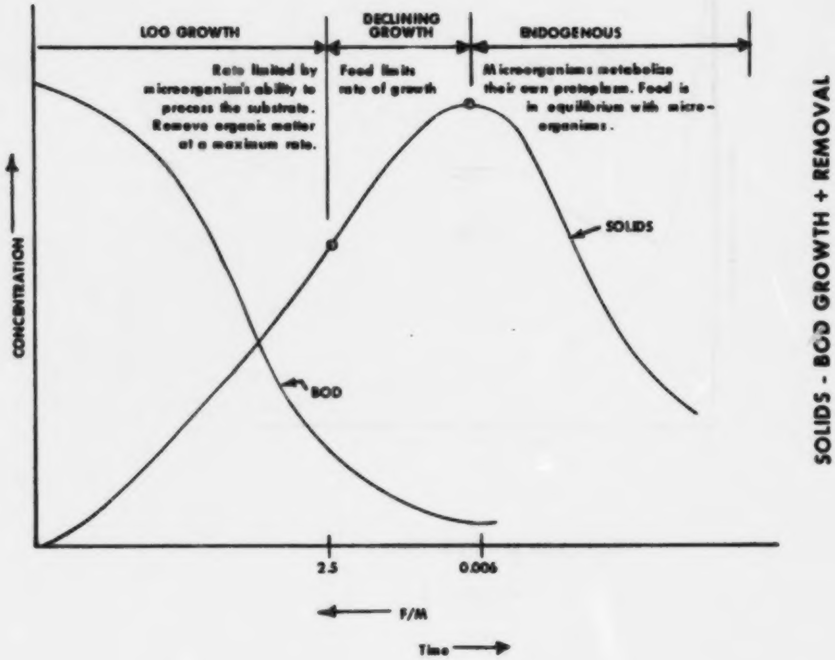
Effluent BOD_5 = L + CS

S = effluent susp. solids

L = effluent soluble BOD_5

C = mg/l BOD_5/mg/1SS (suspended solids)

Figure 3



c Soluble BOD_5 in effluent is function of:

1) Detention time

2) Temperature

3) MLVSS(Sa)

4) lbs of BOD_5 removed/lb MLVSS-day

d Soluble BOD_5 can be computed from the relation

$$L/Lo = 1/1 + KS_a t$$

L = effluent soluble BOD_5

L_o = influent soluble BOD_5

K = lb BOD_5 removed/lb MLVSS-day

S_a = MLVSS

t = Detention time, days

K is a function of temperature and effluent BOD_5. It can be estimated from the relation

$$K = \frac{C_1 L}{C_2 + L} \text{ day}^{-1}$$

where $C_1 = 0.1$ and $C_2 = 80$ for domestic sewage.

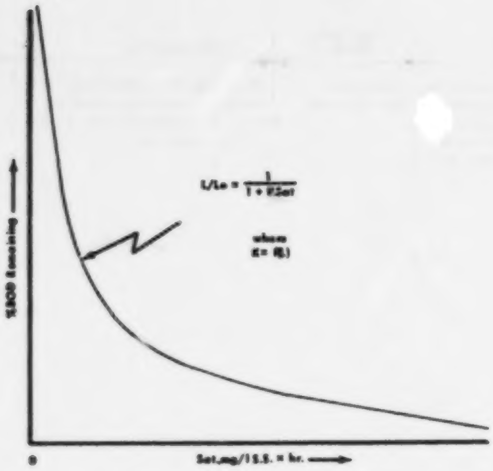
Temperature effect can be measured by

$K_t = K_{20} - O^{T-20}$ where O is approximately 1.0 - 1.04 for activated sludge systems.

Figure 4 illustrates a typical BOD removal

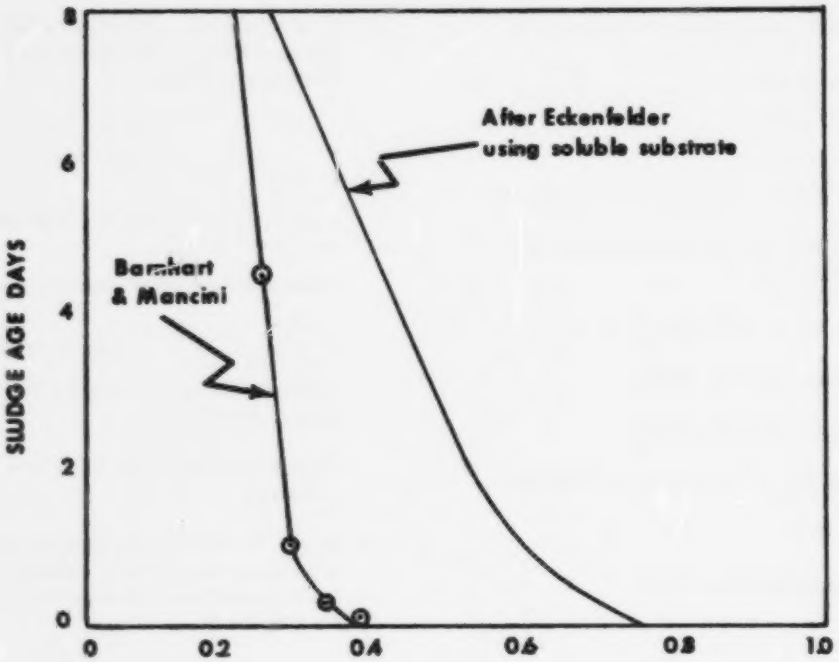
e BOD_5 of the effluent solids will vary with aeration time or sludge age. Wide variation is reported as illustrated on Figure 5.

Figure 4



TYPICAL BOD REMOVAL CURVE

Figure 5



h No sludge digestion problems

i High degree of treatment with proper operation

j No odors generally

2 Cons

a Requires constant operation and maintenance

b Power costs high

c Cost of treatment high

D Design

1 State requirements will generally dictate design. Typical values are listed below.

a Aeration tank

1) Detention time - 24 hr

2) Organic loading - 15 - 25 16 BOD_5/1000 ft^3

3) Air - 1,500 - 2100 ft^3/16 BOD removed

b Settling tank

1) Detention time - 4 hr

2) Surface overflow - 200-300 gpd/ft^2

3) Weir discharge - 600 - 2,600 gpd/ft

4) Sludge return pumping capacity 3 × average daily flow

E Efficiencies

1 Laboratory data from 59 of 1224 plants surveyed by PHS show a wide range of efficiencies

BOD_5 - 99.3 to 33.3 average 86

SS - 96.5 to 0 average 62

2 Related directly to operation and more specifically solids

REFERENCES

1 Package Sewage Treatment Plants Criteria Development Part I: Extended Aeration. National Sanitation Foundation, Ann Arbor, Michigan. September 1966.

2 Eckenfelder, W.E., New Design Advances in Biological Treatment of Industrial Wastes. Oklahoma Industrial Wastes and Pollution Control Conference. November 15-16, 1966.

3 McKinney, R.E., Microbiology for Sanitary Engineers. McGraw-Hill. 1962.

4 Operating Manual for Small Extended Aeration Activated Sludge Treatment Plants. Massachusetts Health Research Inst. December 1961.

5 A Study of Small Complete Mixing Extended Aeration Activated Sludge Plants in Massachusetts. New England Interstate Water Pollution Control Commission. December 1961.

6 Mann, E.P., Design and Maintenance of Extended Aeration Sewage Treatment Plants. Public Works Vol. 95, No. 1. January 1964.

7 Caron, Andre, Operation and Maintenance of Extended Aeration Plants. Public Works, Vol. 96, No. 7.

8 Operating Manual for Small, Extended Activated Sludge Treatment Plants. Oregon State Sanitary Authority. March 1966.

9 Kiher, J.E., Package and Subdivision Sewage Treatment Plants. Journal Water Pollution Control Federation, Vol. 32, No. 8. August 1960.

10 Packaged Aerobic Sewage Disposal Plants, the Surveyor and Municipal Engineers. March 28, 1964.

11 McCarty, Perry L. and Broderson, D.F., Theory of Extended Aeration Activated Sludge. JWPCF, Vol. 34, No. 11. November 1962.

12 Stewart, M.J. and Ludwig, H.F., Theory of the MAS Wastewater Treatment Process. Parts I and II, Water and Sewage Works. March and April 1962.

This outline was prepared by B. David Clark, Sanitary Engineer, Pacific Northwest Water Laboratory.

MECHANICAL SYSTEMS FOR TERTIARY TREATMENT

I INTRODUCTION

A Purpose - Present data on waste treatment systems which provide varying degrees of tertiary treatment.

B Topics of Discussion

1 Filtration

2 Sedimentation

3 Integration of filtration and sedimentation into efficient waste treatment systems producing tertiary effluent quality

II FILTRATION OF SECONDARY EFFLUENTS

A Surface Filtration Devices - Diatamaceous earth, microstrainers; too sensitive to variations in suspended solids concentrations in secondary effluent.

B Slow Sand Filters - Produce high quality effluent but require large land area and high maintenance.

C Review Rapid Sand Filter

1 During backwash, finest sand rises to top of filter.

2 As a result, only top few inches of filter are effective.

3 Floc storage capacity is limited.

4 Sensitive to surface blinding.

5 Any particle passing the first few inches will probably escape.

D Review of Coal-Sand Filter

1 One approach to increasing effective filter depth.

2 Stratification of the discrete layers prevents full filter depth from being effective.

E Review of Mixed-Media Filter

1 The slide actually represents an ideal filter graded uniformly from coarse to fine in the direction of flow.

2 Approach this ideal very closely with mixed-media filter design.

3 Three filter materials used - coal, sand, garnet.

4 Particles are sized so that intermixing occurs at the interfaces and discrete layers are not maintained. This avoids the stratification seen in Slide 2 and allows true in-depth filtration.

5 Mixed-media filter forces effluent to pass through a final barrier of 0.15 mm garnet which is much smaller than the 0.45 mm sand used in a coal-sand filter.

F Applications of Mixed-Media Filtration in Tertiary Sewage Treatment

1 Plain straining

a No chemical coagulants used - merely straining

b Purpose - Remove suspended solids and related BOD

c Efficiency dependent upon degree of flocculation achieved in secondary plant

1) Trickling filter - poor flocculation, 30-50% removal of secondary effluent suspended solids

2) Activated sludge - removal of secondary effluent suspended solids dependent upon organic loading and aeration time. For domestic sewage, 6-8 hours aeration - 65-80% of suspended solids can be removed from secondary effluent by plain

straining; more than 12 hours aeration - more than 90% removal.

d Filtration rate - determined by anticipated quality of secondary effluent. Normally use 5 gpm per square foot. Filter runs of 12-24 hours normal. If plant consistently produces good effluent (< 30 mg/l suspended solids) may use rates as high as 10 gpm per square foot.

e Does not, of course, remove soluble organics or soluble inorganics, such as phosphate.

2 Coagulation and direct filtration

a This is a process originally used at South Lake Tahoe.

b To reduce phosphates, coagulation of secondary effluent can be used.

c Can apply coagulant such as alum directly to mixed-media filters. Two filters in series used to handle these high solids loadings.

d Following coagulation and filtration, filter effluent BOD <1, SS <1, turbidity <1, PO_4 <1 but some residual COD (about 40 mg/l) and color remain.

e These soluble organics can be removed by passage through columns of granular carbon. Carbon is regenerated and reused.

f If secondary clarifier upsets severely and discharges several hundred mg/l suspended solids to filters, filter run become too short. Thus, direct filtration feasible only if secondary effluent is consistently good.

3 Coagulation, settling, and filtration

a This is process now in use at the Tahoe Plant (7.5 mgd).

b Settling of coagulated effluent used to provide buffer zone between secondary clarifier and rest of tertiary process during plant upsets.

c Lime is now used as a coagulant because it can be economically recovered and reused and alum could not.

d High pH resulting from lime coagulant allows NH_3-N to be removed by air stripping.

e Stripping tower effluent recarbonated, filtered, passed through carbon.

f Final effluent very low in SS, BOD, PO_4, turbidity, COD, color, and N.

III SEDIMENTATION

A Description of systems which apply basic settling theories

1 Basic theory of settling says that if settling basin shallow enough, that detention times of only 5-10 minutes would be adequate.

2 Basic theory

a Cross section of horizontal flow, ideal rectangular basin of depth h_o and length L_o.

b Flow is left to right.

c Dashed line is settling path of particle with settling velocity V_o and horizontal velocity V. This particle would be removed in this basin.

d Particle with slower settling velocity V_s would not be removed, but could be if tray or false bottom inserted at depth h.

e If h reduced further, basin size can be reduced further.

f This is basic argument presented in 1904 by Hazen in his proof that settling basin efficiency is independent of detention time and is dependent only on basin depth and overflow rate.

g Tray settlers of the early 1900's were attempts to apply this theory but two major problems limited their success.

  1) Minimum tray spacing limited by that needed for mechanical sludge removal equipment.

  2) Flow distribution problems with wide, shallow trays.

h These problems have been overcome by use of small diameter tubes rather than wide shallow trays and sedimentation basins with total detention times of only 6 minutes can be used.

3 Tube settling

a This is photo of four tube settlers in operation. Tubes are 1 inch in diameter, 2 feet long. Flow is left to right. Influent was alum-coagulated water with turbidity of 300 JU. Total settling detention time is 3 minutes.

b Photo approximates a time-lapse picture. Top tubes just placed in service while second from top has been running longer, third even longer, and the bottom tube longest.

c Can be seen how tubes remove and store floc. Essentially, entire tube volume used for floc storage before any significant carryover occurs.

d Sludge removal - periodic drainage of tube reservoir. Water level falls at a rate such that sludge deposits are hydraulically scoured from tubes. Filter backwash water used to refill tube reservoir.

e Tubes are normally hexagonal in shape and nested together in a honeycomb pattern.

  1) This slide shows one tube configuration used - 2 inch deep tubes, about 4 feet long.

  2) Flow passes through tubes which act as multitude of 2 inch deep basins in parallel.

  3) Imagine all these 2 inch tubes in one plane rather than being nested. These nested tubes are equivalent to a 2 inch deep basin with that surface area.

  4) Tremendous wetted perimeter relative to wetted area. Results in laminar flow. Minimizes flow distribution problems.

IV SYSTEMS INTEGRATING TUBE SETTLING AND MIXED-MEDIA FILTRATION

A Effluent Polishing

1 System in this slide shown with package plant. Process applicable to larger plants as well.

2 Package plants frequently discharge large quantities of solids due to poor operation. This polishing system prevents upsets from reaching the receiving stream.

3 Trace flow through the polishing unit.

4 Tube settler serves as supplemental solids separator. If package plant effluent applied directly to filter, any filter will blind immediately during a plant upset. Tube settler allows filter to operate efficiently even during an upset. Total detention time in tube settler about 15 minutes.

5 Backwash flow pattern.

a Tubes drained completely for sludge removal at start of each backwash cycle.

b Filter backwash returned to secondary plant except last portion is diverted to refill tube reservoir.

c Incoming sewage flow is stored in collection sump during the 7-10 minute cleaning cycle.

6 Effluent quality - BOD <5, SS <5, turbidity <5.

7 Photo of typical unit - 12,000 gpd capacity.

8 A 20,000 gpd plant serving a U.S. Forest Service and Job Corps installation has been in operation since Fall, 1966. Another unit was installed by the Corps of Engineers at a recreational reservoir in Illinois.

B Phosphate Removal

1 Of course, the polishing process discussed above (IV, A) doesn't remove PO_4.

2 Schematic of package system to remove PO_4 is shown in next slide. Chemical coagulation and flocculation have been added ahead of the tube settler and filter.

3 This package would be integrated into a secondary system in a manner similar to that shown for the unit in Slide 9.

4 Effect of very compact tube settling system on plant size well illustrated in next slide. This is a 100 gpm plant with overall dimensions of 6 feet by 6 feet by 14 feet - includes flocculation, settling, filtration, required pumps, chemical feed equipment, and automatic controls.

5 Top view of unit.

a Flocculator, tubes, filter can be seen.

b Completely open on top for easy observation, maintenance.

6 Such a unit is in operation at Ely, Minnesota, at an FWPCA installation (30,000 gpd). Two more units to be in operation in early 1968 in Western Pennsylvania.

C Steeply Inclined Tubes

1 In testing the effects of angle of tube inclination on tube efficiency, we found that if angle of inclination is steep enough (45-60 degrees) that the solids which settle to the bottom of the tubes will slide downward along the tube bottom and exit the tubes.

2 These steeply inclined tubes do not need to be drained or backflushed for sludge removal. Sludge is continuously removed by this natural cleaning phenomena.

3 One of the first applications examined for these steeply inclined tubes was separation of mixed liquor. Slide 14 is a schematic of plant utilizing these tubes.

a Raw sewage, comminuted, enters 12 hours aeration basin.

b Mixed liquor passes up through steeply inclined tubes. Floc drops to tube bottoms and slides down to exit tubes. All sludge is returned by this means. Total settling unit detention time is about 15 minutes.

c Tube settler effluent is filtered for polishing.

d Plant effluent SS and BOD average less than 5 mg/l. SS has been maintained with tube settler.

e Backwash storage, chlorine contact, and sludge storage tank are all integral part of single, rectangular steel plant.

f Overall plant size less than conventional extended aeration plant of same capacity.

g During backwash cycle, aeration basin serves as surge storage also - the level rises.

  - h Filter is backwashed to sludge storage tank which results in some continuous sludge wasting. Reduces frequency at which operator must transfer excess sludge from aeration tank to sludge storage tank.

4 Another application of steeply inclined tubes is upgrading of trickling filter plant performance.

  - a Trickling filter plant efficiency limited by soluble BOD passing through filter.
  - b Can remove this soluble BOD by activated sludge treatment of tf effluent.
  - c In some cases, can accomplish activated sludge treatment and solids separation in the existing secondary clarifier as shown in Slide 15.
  - d 150, 000 gpd plant converted in Summer of 1967. With $1\frac{1}{2}$ hours of aeration, 10 minutes of tube settling, all within existing secondary clarifier, getting essentially complete removal of soluble BOD. Filtration of tube effluent produces final effluent BOD and SS of 5 mg/l or less.
  - e Upgrades tf plant performance from 85% to 95% or more.
  - f Picture of tube module being installed in secondary clarifier.

This outline was prepared by Gordon Culp, Research Manager, Neptune MicroFLOC, Incorporated, Corvallis, OR 97330.

SEWAGE LAGOONS

I TYPES

A Anaerobic

B Facultative

C Non-overflow

D Aerated

E Oxidation Ditch

II ANAEROBIC LAGOONS

A Process Description

1 Single stage, unmixed, unheated digestor

2 Organic matter + bacteria → organic acids + bacteria → CH_4 + CO_2 + intermed. products.

B Factors of Influence

1 Size

a Small surface area to minimize land area and heat loss.

b As deep as possible to maintain anaerobic conditions and save land.

c Depth limited by economics and temperatures. Generally depth 8 ft. or greater.

2 Loading

a Varies from as low as 0.36 to as high as 320 lb. VS/day/1000 ft^3.

b Advantage lies with high loadings because of less land required and better buffering.

c On surface basis, loading varies from 400 to 4000 lb. BOD/acre-day.

d Detention time 8-10 days.

e Determined by rate of solids buildup.

3 pH

a Necessary to maintain pH in narrow range of 6.8-7.2 for optimum operation.

b Adequate alkalinity should be present to buffer against over-production of acids that lower pH.

4 Mixing

a Mixing will improve operation of lagoon because of making more solids effective in biological activity.

b Gas evolution will mix partially.

c Thick scum layers may develop without mixing.

5 Gas production

a Gas production is good sign of an active lagoon.

b Eight to ten ft^3 gas/lb. VS destroyed.

c Sixty to seventy percent of gas is methane (CH_4); remainder is mainly CO_2.

d May get odorous H_2S if waste high in sulfates.

6 Temperature

a Important effect on rate of biological activity.

b Oswald indicated minimal production at temperatures less than 12-13°C with maximum at temperature 719°C. See Figure 6.

7 Solids removal

a Anaerobic lagoons will destroy 50 to 60 percent of the volatile solids in raw domestic sewage. The remainder will accumulate and fill the lagoon.

C Application

1 High strength wastes such as meat packing, other industrial, animal wastes.

2 First stage in a lagoon series.

D Pros and Cons

1 Pros

a High loading rates with up to 70% BOD removal.

b Little land required.

c Operation costs minimal

d Capital costs low

2 Cons

a Poor quality effluent that is not suitable for direct discharge to a stream.

b Requires additional treatment unless discharge is to ground.

c Operation dependent on seasonal temperatures. At temperatures below 12-13°C, pond acts only as a primary sedimentation unit with 30-40 percent BOD reduction.

d pH dependent

III FACULTATIVE LAGOONS

A Process Description

1 Lagoons consist of anaerobic systems on the bottom and aerobic systems on top.

2 Aerobic reactions

Autoflocculation (settling of Ca and Mg at high pH).

Organic matter + bacteria + $O_2 \rightarrow CO_2 + H_2O$ + protein + bacteria $\rightarrow NH_4$ + bacteria $\rightarrow NO_3$

NO_3 + algae + CO_2 + sunlight $\rightarrow O_2 + H_2O$

H_2S + bacteria $\rightarrow SO_4$

3 Anaerobic reactions

Settleable solids + bacteria → organic acids + bacteria

Organic acids + bacteria $\rightarrow CH_4 + CO_2$ + bacteria

NO_3 + bacteria $\rightarrow N_2 \nearrow$

SO_4 + bacteria $\rightarrow H_2S \nearrow$

4 Figure 2 illustrates system.

B Factors of Influence

1 Photosynthesis

a Reaction: algae + sunlight + $O_2 \rightarrow O_2 + H_2O$ + algae

b Function of

1) light intensity

2) duration of light

3) temperature

4) nutrients

2 Temperature

Figure 3 indicates temperature effect on oxygen production (after Oswald).

3 Loading

a Lagoon loaded at 20-50 lb. BOD_u/acre per day.

b Loading should be based on ultimate BOD rather than conventional 5-day.

4 Size

a Area based on loading

b Depth held at 3-5 ft. by requirements.

c No disadvantage to greater depths; i.e., approximately 6-8 ft

C Application

1 Areas where adequate sunshine and land is available.

2 Where algae solids not limiting.

D Pros and Cons

1 Cons

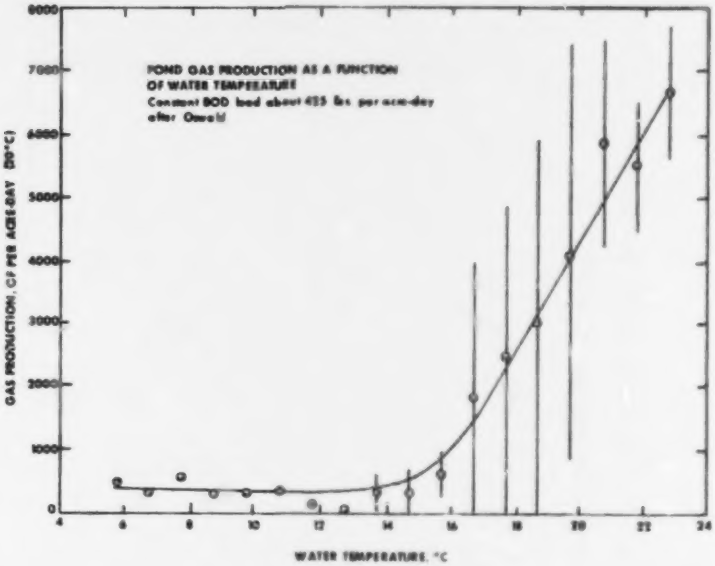
a Low operating and maintenance costs

b Unskilled operator required

c Low capital costs if land cost low

d High quality effluent if algae not limiting.

Figure 1



RELATIONSHIP BETWEEN TEMPERATURE AND GAS PRODUCTION IN PONDS

Figure 2

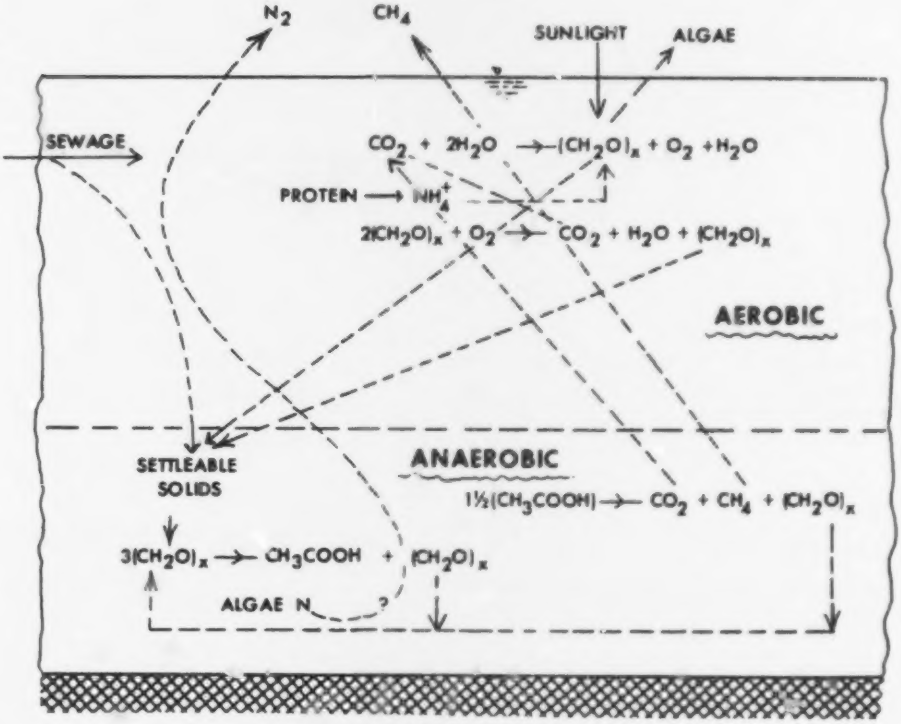
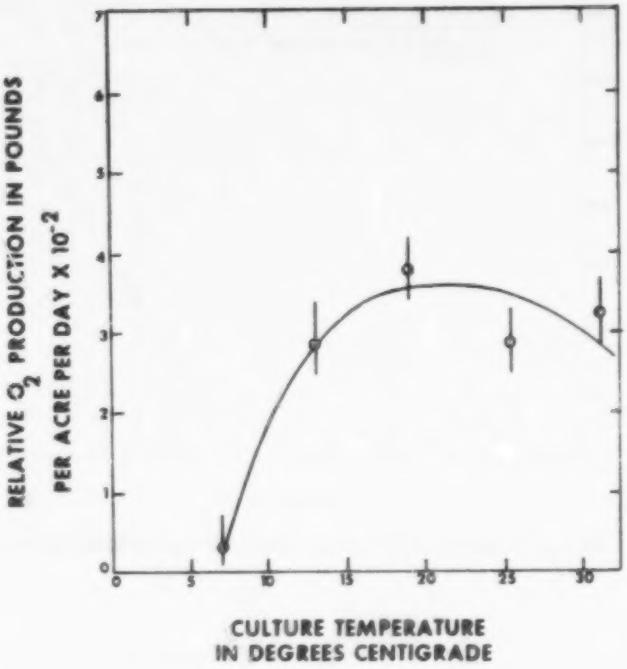

N2
CH4
SUNLIGHT
ALGAE
SEWAGE
CO2 + 2H2O → (CH2O)x + O2 + H2O
PROTEIN → NH4+
2(CH2O)x + O2 → CO2 + H2O + (CH2O)x
AEROBIC
ANAEROBIC
SETTLEABLE SOLIDS
1½(CH3COOH) → CO2 + CH4 + (CH2O)x
3(CH2O)x → CH3COOH + (CH2O)x
ALGAE N
?

Figure 3



RELATIONSHIP BETWEEN ALGAL CULTURE TEMPERATURE AND OXYGEN PRODUCTION IN PONDS
(after Oswald)

E Design

1 Work done by Oswald published in ASCE Transactions, Vol. 122, page 73 describes a design method that takes account of the many variables involved.

IV Non-overflow

A Process description

1 Facultative lagoon with no overflow.

2 Balance made between inflow and outflow.

B Design Parameters

1 Sewage flow

2 Precipitation

3 Evaporation

4 Seepage

Sewage flow + precipitation = evaporation + seepage

C Pros and Cons

1 Pros

a No effluent

b Little operation and maintenance

c Low costs if land cost is low

2 Cons

a Large land areas required

b Design parameters not measurable with any accuracy except flow.

V AERATED LAGOONS

A Process Description

1 Raw waste flows directly to an aeration lagoon. Air is introduced by mechanical surface aeration or diffused air.

B Types

1 Complete mix

2 Facultative

3 Difference between two systems is in power input. Complete mix system maintains all solids in suspension where facultative maintains only a portion of the solids in suspension.

C Factors of Influence

1 Size

a Surface area sized by aerator turbulence influence rings.

b Depth maintained at 8-15 ft. generally

2 Loading

a Approximately ten times conventional lagoon.

b Varies from 80 to 10,000 lb. BOD/acre per day.

c Literature reports loadings of 80 to 2700 lb. BOD_5/acre/day for domestic sewage.

3 Solids

a Equilibrium solids in complete mix lagoon can be estimated from the relation

$$S_a = \frac{S_o + aLr}{1 + bt}$$

where S_a = equilibrium suspended solids, mg/l

a = fraction of BOD_6 converted to solids

Lr = mg/l BOD_5 removed

b = fraction of solids destroyed, day^{-1}

t = detention time, days

S_o = influent suspended solids, mg/l

b In facultative lagoon suspended solids will be on the order of 50-75 mg/l.

4 BOD removals

a Same relationship as was given previously for extended aeration plants

$$\frac{L}{L_o} = \frac{1}{1 + KS_a t}$$

holds for soluble BOD

b Total BOD includes BOD from solids which can be computed from previously given relationship.

5 Oxygen requirements

a Oxygen requirement is given by relation

$$O_z = a'L_r + b'S_a + B$$

where O_2 = total oxygen required

a' = $\frac{1-1.42K_i a}{K_i}$

K_i = ratio of ultimate BOD to 5-day BOD on influent sewage. Approximately 0.68 for domestic sewage

b' = 1.42b

B = bottom demand, lb. O_2/ft^2

b Bottom demand can be neglected for complete mix systems.

c $a'Lr + b'S_a$ can be approximated closely from the relation 1.2 - 1.4 lb. BOD_5 removed/day.

d Eckenfelder states that 3-10 Hp/10^6 gallons will generally supply uniform oxygen distribution.

6 Oxygenation - mechanical surface aerators

a Manufacturers equipment is rated in lb. O_2/Hp-hr. at 20°C, O residual lagoon D.O. and 1 atm pressure.

b Adjustment can be made to operating condition by the relation

$$N = N_6 \frac{C_{sw} - C_1}{C_s} \cdot 1.02^{T-20} \cdot \alpha$$

where N = oxygen transfer rate at operating conditions
N_o = rated oxygen transfer
C_{sw} = D.O. saturation at temperature T
C_1 = lagoon operating D.O.
C_s = D.O. saturation at 20°C
T = temperature at operating condition
α = ratio of oxygen transfer in waste to that in tap water

c Residual D.O. should be 1 to Z mg/l in lagoon.

d α will vary with turbulence, detergents in waste and type of waste. Approximately 0.9 for domestic waste.

e Efficiency of aerator varies with Hp/volume ratio. See Figure 4.

7 Mixing

a Minimum velocity on the order of 0.1 fps or 4 to 8 times the sludge settling velocity necessary to maintain sludge in suspension.

b Horsepower requirements vary with lagoon diameter.

0.02 - 0.03 hp/1000 gal.@ 14 ft. radial dist.

0.05 - 0.06 hp/1000 gal.@ 35 ft. radial dist.

c Figure 5 illustrates relative degree of mixing vs Hp/1000 gal. in the basin to maintain uniform D.O. and to maintain activated sludge in suspension. This curve applies only to weak wastes such as domestic sewage. As waste strength increases the power requirements for uniform D.O. approaches the mixing requirements.

8 Temperature

Same as given previously

D Application

1 Used extensively at present in industrial waste treatment particularly pulp and paper wastes and food processing wastes.

2 McKinney reports on use of two lagoons to treat domestic wastes. Following data is taken from his study (see reference list).

Loading lb. BOD_5/ acre/day	Detention time days	Effluent BOD_5 mg/l	% BOD Reduction
880	7.1	50	78
2,730	1.7	58	66

3 Olson reports use of aerated lagoon to treat domestic waste at low temperatures in North Dakota. At loading of 300 lb/acre/day nearly 90% BOD reduction was obtained at a temperature below 5°C (see reference list).

4 Reid reports on an aerated lagoon used in Alaska. At loadings of 80-115 lb. BOD_5/acre/day, 66 to 81% BOD removals were obtained under subzero operating conditions.

E Pros and Cons

1 Pros

a Construction cost low

b Operation minimal

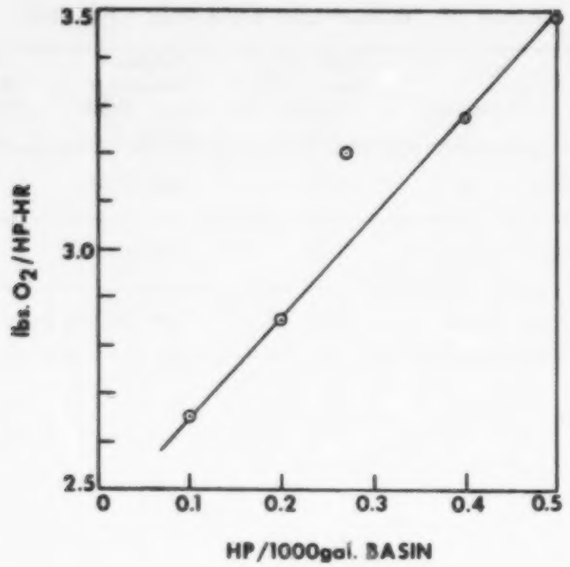
c Operation - maintenance costs low

d Land requirements not excessive

2 Cons

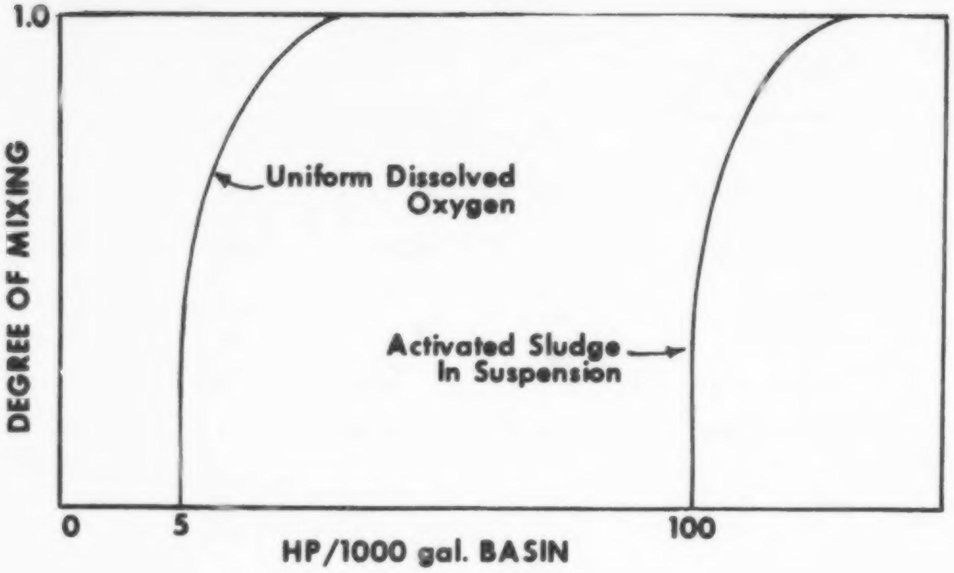
Effluent solids high

Figure 4



EFFECT OF BASIN VOLUME ON OXYGENATION EFFICIENCY

Figure 5



EFFECT OF POWER LEVEL ON MIXING (after Eckenfelder)

Figure 6

RANGE OF DESIGN CRITERIA FOR LAGOONS

Type of Pond	Depth ft.	Hydraulic Detention Time days	Organic Loading lbs. BOD acre-day	BOD Removal Efficiency %
Anaerobic	>8	8-10	400-4000	70
Facultative	3-5	90	20-50	85-95
Aerated Lagoons	8-12	3-20	80-10,000	60-95

Figure 7

SYSTEM COMPARISON

Parameter	Package Extended Aeration	Facultative Lagoon	Non-overflow Lagoon	Aerated Lagoon
BOD_5 Removal	95	99	100	90
Suspended Solids Removal	95	High in algae	100	Low
Total Nitrogen Removal	5	85-95	100	5
Total PO_4 Removal	5	60-90	100	5
Operation	8	1	1	2
Land Area	1	16	36	2
Capital Costs	1.8	1.6	2.4	1
Annual Costs	2.4	1.05	1.4	1

VI OXIDATION DITCH

A Process Description

1 Similar to complete mix activated sludge plants, except aeration solids kept at higher levels.

2 Generally consists of a relatively shallow circular ditch, concrete lined, that uses a rotor aerator to provide oxygen and circulation. Followed by a clarifier with sludge return facilities.

B Process Fundamentals

1 BOD removal

Same as given previously.

2 Solids

Aeration solids are maintained between 4000 to 8000 mg/l compared to 2000 to 4000 for extended aeration.

3 Loading

a Organic loading varies from 0.05 to 0.1 lb. BOD_5/day/lb. MLVSS.

b Detention time is approximately 30 hours.

C Application

1 Widespread use in Europe for treating municipal wastes.

2 Two in Oregon at present

a Beaverton - Textronix, Inc.

b Stayton municipal plant

3 Efficiency depends on ability of clarifier to remove solids with good solids removals, BOD reduction is 92-97%.

D Pros and Cons

1 Pros

a Simple operation and maintenance

b Ability to withstand shock loads

c Low capital costs

d Low operation costs

e Little land required

2 Cons

a Careful control of hydraulic submergence of rotor aerator.

b Skilled operator

VII CURRENT LAGOON DESIGN CRITERIA

A State regulations should be reviewed before design of any system.

B Values given in Figure 6 are ranges of figures currently used.

VIII SYSTEM COMPARISON

A Types

The following systems that have been discussed previously are compared according to efficiency, land requirements, operation-maintenance and costs.

1 Package extended aeration

2 Facultative lagoon

3 Non-overflow lagoon

4 Aerated lagoon

B Comparison

Figure 7 indicates this comparison.

REFERENCES

1 Bhaskaran, T.R., and Chakrabarty, R.N. Pilot Plant for Treatment of Cane Sugar Waste. Journal Water Pollution Control Federation, 38, 7, 1160. July, 1966.

2 Blosser, Russ. Aerated Lagoon Experience in the Pulp and Paper Industry. PNW News Letter. August 1966.

3 Clark, Charles E. Hog Waste Disposal by Lagooning. Journal of the Sanitary Engineering Division, ASCE. Vol. 91, No. SA 6. Proc. Paper 4567. pp. 27-42. December,1965.

4 Dietz, J. C., Clinebell, P. W., and Strub, A. L. Design Considerations for Anaerobic Contact Systems. Journal Water Pollution Control Federation, 38, 4, 517. April, 1966.

5 Eckenfelder, W. W., Jr. Design and Performance of Aerated Lagoons for Pulp and Paper Waste Treatment. 16th annual Industrial Waste Conference.

6 Fall, E. B. Retention Pond Improves Activated Sludge Effluent Quality. JWPCF, Vol. 37, No. 9. p. 1194.

7 Fisher, C. P., and Gloyna, E. F., Treatment of Activated Sludge in Stabilization Ponds. JWPCF. Vol. 37, No. 11. p. 1511.

8 Geldreich, E. E. Bibliographic: Sanitary Significance of Fecal Coliforms in the Environment. Cincinnati Water Research Laboratory, Dept. of the Interior, Cincinnati, Ohio. WPC Research Series Publication No. WP-20-3. November, 1966.

9 Geldreich, Clark and Huff. A Study of Pollution Indicators in a Waste Stabilization Pond. JWPCF. Vol. 36, No. 11. November, 1964.

10 Golueke and Oswald. Harvesting and Processing Sewage-Grown Planktonic Algae. JWPCF. Vol. 37, No. 4. p. 471.

11 Golueke, Oswald and Gee. Increasing High-Rate Pond Loading by Phase Isolation - Final Report. University of California Publication.

12 Hart, S. A. and Turner, M. E. Lagoons for Livestock Manure. JWPCF. Vol. 37, No. 11. p. 1597.

13 Loehr, R. C. Effluent Quality from Anaerobic Lagoons Treating Feedlot Wastes. JWPCF. Vol. 39, 3, 384. March, 1967.

14 McGarry, Michael G, and Bouthillier, Patrick H., Survival of S. Typhi in Sewage Oxidation Ponds. Journal of the Sanitary Engineering Division. Vol. 92, No. SA4, Proc. Paper 4878. pp. 33-43. August, 1966.

15 McKinney, Ross E., and Benjes, Henry H., Jr. Evaluation of Two Aerated Lagoons. Journal of the Sanitary Engineering Division, ASCE. Vol. 91, No. SA6, Proc. Paper 4589. pp. 43-56. December, 1965.

16 Meron, A., Rebhun, M., and Sless, B. Quality Changes as a Function of Detention Time in Wastewater Stabilization Ponds. JWPCF. Vol. 37, No. 12.

17 Neel, McDermott and Moday, Jr. Experimental Lagooning of Raw Sewage at Fayette, Missouri.

18 Olson, Omar O., Van Heuvelen, Willis, and Vennes, John W. Aeration of Potato Waste. 19th Industrial Waste Conference.

19 Potos, Chris. Removal of Algae from Wastewater Maturation Pond Effluent. JWPCF. Vol. 37, No. 9. p. 1256.

20 Rollag, D. A., and Dornbush, R. N. Design and Performance of an Anaerobic Stabilization Pond System for Meat-Processing Wastes. JWPCF. Vol. 38, No. 11. p. 1805. November 1966.

21 Williford, Howard K., and Middlebrooks, E. Joe. Performance of Field-Scale Facultative Wastewater Treatment Lagoons. JWPCF. Vol. 39, No. 12. pp. 2008.

22 A Review of Research and Experience in the Design, Construction, Operation and Maintenance of Waste Stabilization Lagoons. U. S. Public Health Service, Water Supply and Pollution Control Activities, Region VI, Proceedings of Symposium on Waste Stabilization Lagoons, Kansas City, Missouri. August 1-5, 1960.

23 Advances Toward Understanding Lagoon Behavior. Proceedings of the Third Annual Sanitary Engineering Conference. Engineering Extension Series, No. 6. November 9, 1966.

24 Stabilization Ponds for a Small African Urban Area Hodgson. JWPCF. Vol. 36, No. 1. January, 1964.

This outline was prepared by B. David Clark, Sanitary Engineer, Pacific Northwest Water Laboratory, FWPCA, Corvallis, Oregon.

SEWAGE LAGOON OPERATION AND MAINTENANCE

I OBJECTIVE

The objective in any domestic waste water treatment process is the removal and stabilization of colloidal and suspended solids and the stabilization of dissolved organic material. In waste water stabilization ponds, these objectives can be accomplished with a minimum of maintenance, operation and cost.

II THE TREATMENT PROCESS

A lagoon may be called a "self-purification" process. Biological activities which occur in a lagoon are similar to those which occur in streams or lakes when large quantities of organic materials are discharged into them. Heavier solids, which may be inert materials or complex organic compounds, settle to the bottom of the pond where the complex organic compounds are broken down into simpler organic and inorganic material by bacterial action. These simpler materials, most of which are soluble in water, become food for other bacteria and thus are converted into additional inorganic material and more stable organic compounds.

A Aerobic - Anaerobic

The terms "aerobic" and "anaerobic" are commonly used to describe the type of bacterial activity which is occurring in any particular pond. In theory, an aerobic pond is one which has free dissolved oxygen throughout its contents. In such a pond the predominant active bacteria would be "aerobes" which only thrive in the presence of free dissolved oxygen.

Also in theory, an anaerobic lagoon is one which has no dissolved oxygen in its contents. In this type of pond, the predominant active bacteria would be "anaerobes" which can thrive in either the presence of, or the absence of, free dissolved oxygen.

In actual practice, most so-called aerobic lagoons are probably a combination of aerobic and anaerobic conditions. The aerobic zone would be near the pond surface where natural aeration by wind action and other factors combine to provide a continuous supply of free dissolved oxygen. The anaerobic zone would be near the bottom of the pond where an excess of organic materials and an absence of reaeration preclude the continuous presence of free dissolved oxygen.

B Bacterial Activity - Oxygen - Algae

When sewage is discharged into a lagoon, the heavy solids settle to the bottom and anaerobic bacteria utilize the solids for food and oxygen supply. The anaerobic bacteria utilize the complex organic compounds for food and obtain oxygen from the breakdown of nitrates, sulfates and carbonates. The by-products of this decomposition process are simpler soluble organic acids, ammonia, hydrogen sulfide, methane, carbon dioxide, and water.

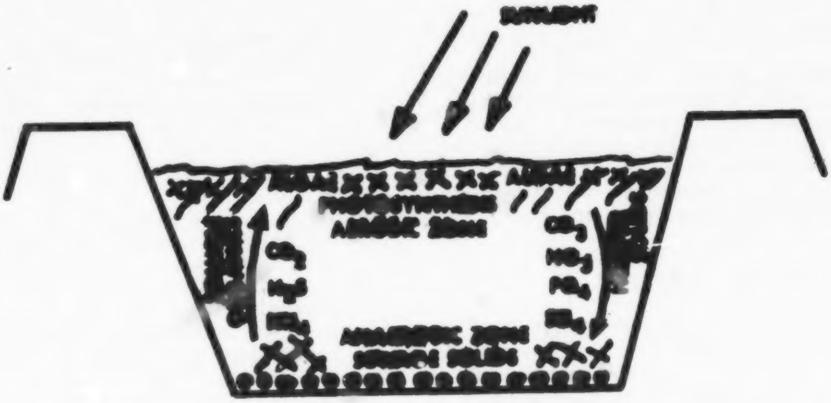
The soluble by-products of anaerobic decomposition are feed material for aerobic bacteria and for algae. Algae require a source of carbon, nitrogen, nutrients and sunlight. When these factors are all satisfactory, algae, through photosynthetic action, produce free oxygen. The free oxygen, of course, is immediately available for use by the aerobic organisms and also is available to chemically react with hydrogen sulfide to form sulfate compounds.

The aerobic organisms, utilizing free oxygen, feed on the soluble organics in the raw waste and on the soluble organic by-products of anaerobic decomposition. In turn, they produce some inert compounds which settle to the bottom and also dissolve sulfate, nitrate, phosphate and carbonate compounds which, it will be recalled, are vital sources of oxygen for the anaerobes living in the lower regions of the pond. So, it may be seen that, in most lagoons, the treatment process is a complex give-and-take interaction between at least two bacterial communities and an algal growth. Following is a schematic description of the action.

C Temperature - Ice Cover

As with any biological process, temperature has a very significant effect on the rate of biological activity in sewage lagoons. At temperatures approaching freezing, the reaction rates are very slow compared with those during normal warm weather (water) periods. Therefore, during

Figure 1



extended cold periods, the organic compounds in the incoming raw waste load are not degraded as rapidly as during warmer periods and consequently a buildup of organic compounds may occur.

When the lagoon temperature is low enough for ice to form on the surface the aerobic degradation process may become completely disrupted. Ice cover prohibits aeration (oxygen intake) by wind action. In addition, ice cover and snow may reduce sunlight penetration to the point where algal growth is negligible, thus cutting off that source of free oxygen. Under these conditions, the aerobes may go into a state of dormancy for the duration of the winter.

The anaerobic organisms, however, continue to function though at a reduced rate due to the lower temperature. The products of anaerobic decomposition continue to form and concentrate under the ice cover. When the ice cover breaks in the spring these trapped odorous materials, particularly hydrogen sulfide (H_2S), coupled with the products of increased anaerobic activity due to the warmer water may cause unpleasant conditions in the immediate and downwind vicinity of the lagoon. Fortunately, dilution water from melting ice, rising air and water temperature, stimulation of algal growth by sunlight, and natural aeration from wind action all combine to revive the dormant aerobic organisms. Normally this recovery will be completed in 1 to 14 days depending on the relative buildup of organic material in the pond during the winter.

D Relative Treatment Efficiency

During summer months when the lagoon is warm and sunlight is abundant, bacterial and algal growth is rapid and lagoon treatment efficiency is normally very high. It is not uncommon to have 95 percent reduction of incoming organic and over 99 percent of coliform bacteria loads. This degree of treatment is better than conventional mechanical secondary treatment. However, during winter months the colder water temperature slows down the biological treatment process. During these periods most of the treatment accomplished is due to solids settling. As mentioned in the previous section, some anaerobic activity will continue, but at a severely reduced rate. The overall treatment efficiency during these periods is, therefore, considerably lower than during summer months.

E Operation for Greatest Overall Efficiency

Most lagoons in Montana are designed and constructed to permit the operator some flexibility in operation. Effluent or overflow structures which permit variable depth operation are usually provided for each pond. If the pond overflows during normal operation at full depth, the variable depth overflow structure can be used to lower the pond two to three feet about October 1, and thus provide for storing practically all winter flows when treatment efficiency is low. Operation in this manner protects the stream from a poorly treated effluent during winter months. It is recommended that lowering the pond be done slowly, about one to two inches per day.

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Many of our lagoon systems have two cells (ponds) and usually they can be operated in either series or parallel. Lagoons operated in series may provide better overall treatment. However, adding all the untreated waste to one cell may result in an overload in that cell and a greater potential for obnoxious odors, particularly in the spring. In some cases, the lagoon cells can be operated in series during the warmer months and in parallel during the colder months and thus minimize odor potential. Each lagoon system has its own operational characteristics and the operator, by trial and error, can determine how it can best be operated to gain maximum efficiency with minimum nuisance.

III OPERATION - PROBLEMS

A Odors

The main problem which has occurred in several of our lagoons has been odors which persist beyond the normal 1 to 14 days immediately following spring ice break up or which continue intermittently throughout the summer. Although the number of lagoon systems which have extended periods of odors is very small, the adverse publicity therefrom is quite voluminous. Most Montana lagoons have a minimum of odor in the spring and none thereafter and some of the systems operate the year around without any odors. This latter group is usually those which either receive large volumes of infiltration water or serve communities where the water supply is low in total dissolved solids (TDS) such as is normally present in Western Montana.

For those operators who have periodic or persistant odor problems, the following suggestions are offered.

1 **Reduction of loading: Lagoons in Montana are normally designed for a maximum loading of 100 people per surface acre. Higher loadings increase the possibility of odors. If additional cells are available, use them. If the loading exceeds 100 people per acre and additional cells are not available, an expansion should be considered.**

2 Lowering lagoon level: In some cases lowering of the lagoon level will permit the lagoon to recover faster in the spring. If the lagoon level is lowered, this should be done as previously described.

3 Chemical treatment: The addition of sodium nitrate has been reported to be of assistance in reducing odors. Application rates of 100 pounds per acre for the first five days and 50 pounds per acre until the odors are eliminated are needed. The application of sodium nitrate preferably should be started as the weather warms and the ice begins melting and should end as algae become visible. The cost of sodium nitrate treatment will be about $100 per acre per season. Sodium nitrate provides a source of oxygen for the bacteria. The use of chemical deodorants is not recommended.

4 Aeration. At lagoons where odors are more persistent and are a nuisance to nearby neighbors, aeration of the lagoons might be considered. The number of lagoons in Montana where aeration should be seriously considered is probably less than five percent of the total number of lagoons. Aeration systems when properly designed and operated should completely eliminate odor nuisances. The cost of such a system is estimated at $10,000 for a lagoon serving 1,000 people. Operational cost is estimated at $200 per year for seasonal operation for a lagoon serving 1,000 people.

B Maintaining Proper Liquid Level

A liquid level of two to three feet is needed in the summer to prevent nuisance aquatic weed growths. For some systems, especially immediately following construction, it may be necessary to add water, in addition to the normal sewage load, in order to maintain proper operating depth. The additional water may be river water or can be added through the sewer system by flushing hydrants and discharging the water into a manhole. Some lagoons, due to inadequate compaction or a lack of scaling material during construction, continue to have a high rate of seepage for a number of years. These lagoons will partially seal themselves with sewage solids and growths; but sometimes it is advantageous to use a sealing material such as bentonite. A well designed and constructed lagoon should have a minimum of seepage.

IV OPERATION - MAINTENANCE

A General

Many of our lagoons receive little or no maintenance, and as a consequence, the lagoon becomes an eyesore and a place for mosquitoes to multiply.

B Weeds and Aquatic Growths

Most lagoons were originally seeded with a crested wheat grass. Where planting of the grass has been successful and the proper lagoon level is maintained, weeds and nuisance aquatic growths are minimal. Where weeds and aquatic growths are present, a chemical weedicide is recommended. When requested, the State Department of Health will furnish recommendations for this chemical treatment. The cost of chemical treatment is estimated at $100 per application for a ten-acre lagoon system. Where grass is poor on the lagoon embankment, considerations should be given to replanting. Contact your county extension agent for his recommendations. The grass should be mowed as needed.

Any evidence of cattails, reeds and willows or other small bushes should be removed immediately. Cattails and reeds steal pond volume otherwise available for treatment and interfere with circulation in the pond. Small trees along the dike may cause excessive seepage by ruining the seal in the dike.

C Erosion Control

Severe erosion problems have occurred in a few instances. The worst erosion normally takes place during the first year of operation. Materials used for erosion control should not interfere with mowing of the embankments nor should they provide quiet water for mosquitoes. The use of old tires, large chunks of concrete or old car bodies is not recommended for riprap.

D Ditch Inspection

The dikes should be inspected at least weekly during open water and at least twice monthly during the winter. Any rodents which may burrow into the dikes should be eliminated as soon as possible.

This outline was prepared by the Division of Environmental Sanitation, Montana State Department of Health.

MONTANA STATE DEPARTMENT OF HEALTH
SEWAGE LAGOON RECORD

Community ____________
Operator ____________
Year ____________

	LAGOON LEVEL Feet of Depth	OVERFLOW Estimated Gallons per Minute	ICE		ODORS		GRASS MOWED Date	WEEDICIDE APPLIED Date	NO. OF INSPECTIONS During Month	REMARKS
			Date Formed	Date Melted	Date Odors Began	Date Odors Ended				
January										
February										
March										
April										
May										
June										
July										
August										
September										
October										
November										
December										

NOTE: 1. Lagoons should be bypassed only when an emergency exists. Prior notification should be given to the State Department of Health before the bypass is used.

2. A copy of this record should be submitted to the State Department of Health at the end of each year. New forms will be sent to the operator each year.

TERTIARY TREATMENT BY MEANS OF LAGOONS AND LAND IRRIGATION PRACTICES

I NON-OVERFLOW LAGOON SYSTEMS

A Factors Affecting Multiple-Cell Lagoon Systems

1 Climatology

Each of the following requires individual attention at each proposed installation as their importance may vary from installation to installation:

a Precipitation

b Evaporation

c Wind

d Sunlight

e Temperature

2 Groundwater

The depth of the groundwater below the ground surface as well as its movement should be seriously studied so as not to endanger any nearby water users.

3 Percolation

Seepage should be minimized other than in the last cell in a series. Serious consideration should be given not only to a potential groundwater pollution problem, but also seepage and formation of springs in the immediate area resulting from a perched water zone beneath the ponds.

B Design Considerations

1 Raw sewage lagoons

a Organic loading - 20-35# BOD/AC/Day

b Minimum water surface - 1/2 acre

c Detention time - 60-100 days

d Water depth - 3-5 feet

e Shape - uniform with no coves

f Freeboard - 3 feet

g Dikes - impervious material with a top width of 8 feet

h Interior slopes - 3-4 ft. horizontal to 1 ft. vertical

i Outlet - and a baffled surface outlet with provision for subsurface withdrawal

j Inlet - submerged at center of the pond

k Flow measurement - continuous flow measurement facilities should be provided

2 Secondary ponds

a Organic loading - not to exceed 50# BOD/AC/Day on any pond

b Detention time - 5-15 days

c Shape - uniform with no coves or islands

d Inlet-outlets - located so as to provide maximum detention and no short circuiting. Submerged inlets, baffled outlets.

II OVERFLOW SYSTEMS

A Effluent Quality

Generally a properly designed lagoon system will provide an effluent with a 5-day BOD of less than 20 ppm. A 99 percent reduction in coliform organisms can also be expected.

B Disinfection

Where effluents are allowed by local authority, continuous chlorination should be practiced.

C Downstream Water Use

Prior to the installation of any lagoon system with an effluent discharge, careful evaluation of downstream uses must be made so as not to endanger any existing or future water uses. In addition, the stream's capacity to receive these wastes must be considered.

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III AGRICULTURAL UTILIZATION OF SEWAGE EFFLUENTS

A Methods of Distribution

1 Spray

This application usually requires pumping facilities as well as a distribution piping system. Since very little land preparation is required, irrigation sprinklers or other types of distribution devices are used depending on the existing terrain and vegetation.

2 Flooding

Flood irrigation in grasslands or relatively flat areas is practiced where intermittent application is desired. Land preparation usually involves leveling and bordering to insure uniform distribution and confinement of the effluent.

3 Ridge and furrow

This method of application is principally used on cultivated areas where distribution is accomplished by means of irrigation canals or piping system. Rotated crops and grasses provide excellent cover and use of sewage effluents.

B Design Considerations

1 Climatology

- a Temperature
- b Precipitation
- c Evaporation
- d Sunlight
- e Wind

2 Soil characteristics

The most important factor in an irrigation system is the ability of the proposed irrigated plot to accept the waste at a satisfactory rate. This may vary from less than 3,000 gallons per acre per day for tight soils to over 10,000 gallons per acre per day in areas where the soil is loose and evaporation high.

3 Effluent characteristics

It is recommended that only primary or secondary domestic sewage effluents be applied in land irrigation systems.

4 Holding facilities

A well-designed sewage irrigation system will have a storage or holding facility of between 10 and 30 days.

5 Rate of application

The determination of how much water can be efficiently and effectively applied to the fields is an important design factor to be considered.

Suggested rates of application:

Sandy loam - 70-80 inches/AC/Year

Sand - 200-250 inches/AC/Year

6 Vegetation

It is generally recommended that field crops, grains and forest areas be used for sewage effluents, unless the effluent is disinfected or otherwise treated for bacteria removal. Only that type of vegetation locally adopted should be considered in an irrigation program.

7 Operation and management

All types of land irrigation systems require continuous supervision in their operation. A continual review of application rates and soils capacity for accepting these wastes is necessary in order to prevent overflows to water courses, effluent killing the vegetation, or causing unwanted odor problems in the area.

This outline was prepared by James C. Willman, Sanitary Engineer, Federal Activities Coordination, FWPCA, Northwest Region.

CHLORINATION PRACTICES

I INTRODUCTION

A Chlorinated lime was first used to deodorize London sewage in 1854. In the United States, Powers was granted a patent in 1887 for a process covering the application of chlorine gas to deodorize and disinfect sewage. In 1909 liquid chlorine was produced. By 1914 it was used for sewage effluent disinfection.

B Free-residual chlorination was developed by Howard in 1929 at Toronto, Ontario but did not receive wide acceptance until it was publicized as 'break-point chlorination' in 1939.

C In 1957, 30% of all municipal sewage treatment plants had chlorination facilities. The larger plants had a higher percentage.[1] Seasonal summer chlorination was the rule.

D In 1968, under the Federal Water Pollution Control Act, all municipal plant effluents will have to be chlorinated before discharging into receiving streams.

II USE OF CHLORINE IN SEWAGE TREATMENT

A Disinfection

1 The most important use of chlorine in sewage treatment is disinfection. This protects water supplies, bathing beaches and fishing areas and prevents nuisance.

2 To be effective, chlorine requires a contact time of not less than 15 minutes at maximum flow rates with a residual of not less than 0.2 to 1.0 milligrams per liter (mg/l).

a This will generally result in a 99.9% reduction in the coliform content of the effluent.

3 The range of chlorine dosage needed for disinfection, mg/l, is as follows:

Raw Sewage	6 - 12
Septic Raw Sewage	12 - 25
Settled Sewage	5 - 10
Septic Settled Sewage	12 - 40
Chemical Precipitation Effluent	3 - 10
Trickling Filter Effluent	3 - 10
Activated Sludge Effluent	2 - 8
Sand Filter Effluent	1 - 5

B Putrefaction and Odor Control

1 Sub-residual amounts of chlorine are used to arrest decomposition of organic matter or to combine with hydrogen sulfide and other odors already formed.

a Four to six mg/l without production of a residual.

C Reduction of BOD

1 Approximately 2 mg/l of 5-day BOD is satisfied by 1 mg/l of chlorine added. This may be more of a BOD test effect than a substrate effect.

2 Chlorine alone can reduce BOD by as much as 15 to 35%.

3 It is not usually economical to use chlorine for BOD reduction.

D Control of Corrosion

1 By prevention of hydrogen sulfide formation, chlorine controls corrosion of iron structures and the deterioration of concrete structures.

a Dosage - 2 to 10 mg/l; higher dose required to eliminate slime growths.

E Grease removal by the addition of chlorine and air

F Improved Trickling Filter Operation

1 Chlorination reduces odors, reduces ponding and controls filter flies.

G Control of Activated Sludge Bulking

1 Chlorination of the return sludge controls bulking caused by filamentous organisms.

a A chlorine dose of 1 to 10 mg/l based on the return sludge flow is required.

H Sludge thickening in the activated sludge process by maintaining a residual of 1.0 mg/l in the superantant.

I Digester and Imhoff Foaming Control by the continuous addition of 3 to 15 mg/l of chlorine to the sewage entering an Imhoff tank or digester.

J Reuse of Sewage Effluents is only possible when chlorination for disinfection is practiced.

III PROPERTIES OF CHLORINE

A Liquid chlorine is an amber-colored, oily fluid 1.5 times as heavy as water. Dry chlorine or gas is non-corrosive to iron, copper or lead at ordinary temperatures. Moist or wet chlorine is highly corrosive to most metals.

B Atomic weight - (Cl) - 35.457, molecular weight - (Cl_2) - 70.914. Boiling point - 30.1°F at normal temperature and pressure (NTP). Specific gravity of the gas is 2.48 at 68°F.

C One pound of chlorine yields five cubic feet of gas at NTP. Under ordinary atmospheric conditions, chlorine gas is a highly toxic, yellowish-green gas which can be detected by smell in concentrations as low as 1 to 3 mg/l.

D Solubility of chlorine varies with temperature; 83.2 pounds (lbs.) of chlorine will be absorbed in 1000 gallons of water at 50°F; 60.8 lbs. at 68°F. At 49.2°F, chlorine hydrate forms, removing chlorine from solution as a solid.

IV METHOD OF APPLICATION OF CHLORINE

A Chlorine is available as a liquid or in the form of chlorine compounds.

B Liquid chlorine is obtained in 100 lb., 150 lb. cylinders, in ton containers or in 16 ton, 30 ton or 55 ton tank cars. Chlorine containers and transportation are governed by Interstate Commerce Commission rules.

C The majority of treatment plants use chlorine bought and stored as a liquid and utilized as a gas.

D Chlorine Compounds

1 Chlorinated Lime - an unstable, dry powder having 35% available chlorine.

2 Calcium Hypochlorite - a stable, dry powder having 70% available chlorine.

3 Sodium Hypochlorite - a solution containing 2 to 15% available chlorine.

a Power plants have used sodium hypochlorite for over 30 years to prevent slime growths in condenser tubes and heat exchangers. Recently New York City abandoned use of liquid chlorine for disinfection of treatment plant effluents and is now using sodium hypochlorite solution.

V HANDLING PRACTICES

A Liquid chlorine requires extraordinary care in handling, shipping and storing. The articles by Laubusch of The Chlorine Institute[2,3] provide a valuable source of information on the safe handling of chlorine.

B For insight into the numerous problems arising in the use of liquid chlorine, the paper by Steffensen and Nash[4] should be read.

VI FEEDING EQUIPMENT

A Chlorine dispensing equipment is designed to control and measure chlorine in the gaseous state and to apply it either as a gas or as an aqueous chlorine solution.

B Gaseous feed permits accurate flow regulation, either manual or automatic; gas can be metered with variable area or fixed orifice type flow meters, with or without recording instruments; and chlorine gas can be diffused into water.

C Direct Feed Equipment

1 Direct feed equipment involves metering of dry chlorine gas and conducting it under necessary pressure conditions to the water being chlorinated.

2 In direct feed equipment, chlorine gas direct from the cylinder passes through a pressure compensating valve and then to a back pressure regulating and check valve designed to maintain a constant downstream metering pressure and to prevent liquid from entering the chlorine line in event of shutdown or the development of excessive back pressures at the point of application.

a The gas is applied directly through some type of diffuser into the water to be treated.

b Since chlorine gas is only slightly soluble in water, 60.8 lbs. in 1000 gallons at 68°F, this limits the rates at which gas can be fed. This limits their use to small installations and this type of equipment is not recommended for safety reasons except under special conditions which prevent the use of solution feed chlorination.

D Solution Feed Equipment

1 Solution feed equipment involves metering of dry chlorine under vacuum or pressure and dissolving it in a small amount of water so that a high strength solution is applied.

2 There are two types of solution feeders, the pressure-feed type and the vacuum-feed type.

a The pressure-feed type uses a mechanical-diaphragm chlorine control valve to reduce the cylinder pressure ahead of the metering device. The metered chlorine gas is fed into an eductor where it is mixed with water and fed to the point of application.

b The vacuum-feed type reduces the cylinder pressure ahead of the metering device by applying a vacuum on the outlet side of the meter. This places the chlorine under a partial vacuum or negative head throughout the system and up to the discharge eductor which lessens the possibility of a chlorine leak. If the water supply to this type of chlorinator fails, the flow of chlorine gas is automatically checked. If the vacuum chamber is broken, the flow of gas is automatically stopped.

c The vacuum-feed type of chlorinator is now in general use.

E Hypochlorite Feeders

1 Hypochlorite feeders are simply chemical feed pumps, diaphragm or piston type, which will inject hypochlorite solutions with feed rates from 0.2 to 57 gallons per hour for discharge pressures up to 125 psi using diaphragm elements or up to 500 psi using plunger elements. Pump-tank combinations are also available.

VII CHEMICAL COSTS

A Liquid Chlorine

1 Delivered cost per pound of available chlorine in New York City is reported as 7 cents per pound[4].

2 Delivered cost in Chicago is $3.80 per cwt (3.8 cents/lb.).

B Sodium Hypochlorite

1 Delivered cost per pound of available chlorine in New York City is reported as 12 cents per pound[4].

2 Delivered cost in Chicago is $8.70 per cwt (8.7 cents/lb.)

VIII COMPARATIVE COSTS

A Chlorination with liquid chlorine has the advantage of low price for the chemical. Higher building costs, however, along with much higher capital costs of the dosing equipment required make the total annual costs almost equal.

B For a more detailed cost comparison, the paper by Steffensen and Nash relating to the New York City conversion from liquid chlorine to sodium hypochlorite chlorination is a valuable source of information[4].

C Where communities can obtain sodium hypochlorite solution in adequate amounts at a reasonable cost, the simple, safe application of sodium hypochlorite for disinfection of wastewater effluents is recommended.

IX CHLORINE DETENTION FACILITIES

A A special contact chamber for intermixing and detention of the chlorinated effluent is used in the majority of treatment plants.

B A contact time of not less than 15 minutes at maximum flow rates with a residual of not less than 0.2 to 1.0 mg/l is required.

C Types of facilities that may be utilized for chlorine intermixing and detention are:

1 Outfall sewer

2 Special contact chamber, unbaffled

3 Special contact chamber, baffled

4 Final settling tank

5 Oxidation pond

6 Receiving waterway

D For large installations, hydraulic model studies of mixing and contact chambers is recommended[5].

X CHLORINATION FACILITIES AT THE CHICAGO METROPOLITAN SANITARY DISTRICT

A Chicago's North Side Treatment Plant chlorination facilities went on stream in July 1967, 1-1/2 years ahead of schedule due to utilization of the effluent conduit and the North Shore Channel for the contact basins.

B Construction costs were cut dramatically. The North Side contract for 300 mgd capacity was $48,573. The Calumet Plant chlorination facilities for 220 mgd capacity under construction will cost $1,844,000.

C With 30 minute detention, the desired bacteria kill can be met with an average chlorine dose of 0.7 mg/l. This is due to the high quality of the plant effluent. Higher dosages, 1.8 mg/l, are being used to offset unknown chlorine demands from bottom deposits.

D The Calumet Plant chlorination facilities will be on stream by the end of 1968, one year ahead of schedule.

E The West-Southwest Plant with a rated capacity of 900 mgd must be on stream by July 1972. It is planned to use 1,000 feet of the Sanitary and Ship Canal for the contact basin since the dilution ratio here is 1 to 1. By using the canal for a contact basin, savings in construction of over $7,000,000 are expected.

F Chicago chlorination facilities are designed to use sodium hypochlorite.

REFERENCES

1 Thoman, J. R., and Jenkins, K. H. Statistical Summary of Sewage Works in the United States. Public Health Service Publication No. 609, 1958.

2 Laubusch, E. J. Chlorine Handling and Storage. Water and Sewage Works. pp. 71-77. February 1959.

3 Laubusch, E. J. Safety in Chlorine Handling. Water and Sewage Works. pp. 169-175. April 1959.

4 Steffensen, S. W. and Nash, N. Hypochlorination of Wastewater Effluents in New York City. Journal Water Pollution Control Federation 39, pp. 1381-1402. August 1967.

5 Louie, D. S. and Fohrman, M. S. Hydraulic Model Studies of Chlorine Mixing and Contact Chambers. Journal Water Pollution Control Federation 40. pp. 174-184. February 1968.

6 Chlorination of Sewage and Industrial Wastes. Manual of Practice No. 4. FSIWA. Washington, D.C. 1951.

This outline was prepared by V. W. Bacon, General Superintendent, Metropolitan Sanitary District of Greater Chicago.

SECTION V

SURVEILLANCE AND OPERATIONAL CONTROLS

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GENERAL NEEDS, REPORTS, AND CONTROL MEASUREMENTS

I PURPOSE

The purpose of a sewage treatment plant surveillance program is to collect and maintain information on the plant process and waste discharge characteristics that may affect the receiving stream or become a public health hazard.

A Water Quality Control

Agencies responsible for developing and maintaining water quality control standards under administrative rules, pertaining to water pollution, developed under statutory authority. These regulations require that the highest and best practicable treatment and/or control of waste, activities and flows shall in every case be provided so as to maintain dissolved oxygen and over-all water quality at the highest possible levels and water temperatures, coliform bacteria concentrations, dissolved chemical substances, toxic material, radioactivity, turbidity, color, odor, and deleterious factors at the lowest possible level. The maintenance of Standards of Quality depend on the level of waste treatment provided.

1 The degree of waste treatment required to restore and maintain the above standards of quality is based upon the following:

   a The uses which are or may likely be made of the receiving stream.

   b The size and nature of flow of the receiving stream.

   c The quantity and quality of the sewage or wastes to be treated.

   d The presence or absence of other sources of pollution on the same watershed.

2 All sewage shall receive a minimum of secondary treatment or equivalent (equal to at least 85% removal of 5-day biochemical oxygen demand and suspended solids) and shall be effectively disinfected before being discharged.

Although there are exceptions, it is generally required that no wastes shall be discharged and no activities shall be conducted which either alone or in combination with other wastes or activities will cause in any waters:

a The dissolved oxygen content of surface waters to be less than six (6) milligrams per liter unless specified otherwise by special standard.

b The hydrogen-ion concentration (pH) of the waters to be outside the range of 6.5 to 8.5 unless specified otherwise by special standard.

c The liberation of dissolved gases, such as carbon-dioxide, hydrogen sulfide or any other gases, in sufficient quantities to cause objectionable odors or to be deleterious to fish or other aquatic life, navigation, recreation, or other reasonable uses made of such waters.

d The development of fungi or other growths having a deleterious effect on stream bottoms, fish or other aquatic life, or which are injurious to health, recreation or industry.

e The creation of tastes or odors or toxic or other conditions that are deleterious to fish or other aquatic life or affect the potability of drinking water or the palatability of fish or shellfish.

f The formation of appreciable bottom or sludge deposits or the formation of any organic or inorganic deposits deleterious to fish or other aquatic life or injurious to public health, recreation or industry.

g Objectionable discoloration, turbidity, scum, oily sleek or floating solids, or coat the aquatic life with oil films.

h Bacterial pollution or other conditions deleterious to waters used for domestic purposes, livestock watering, irrigation, bathing, or shellfish propagation, or be otherwise injurious to public health.

i Any measurable increase in temperature when the receiving water temperatures are 64° F or above, or more than 2° F increase when receiving water temperatures are 62° F or less.

j Aesthetic conditions offensive to the human senses of sight, taste, smell, or touch.

k Radioisotope concentrations to exceed Maximum Permissible Concentrations (MP's) in drinking water, edible fishes or shellfishes, wildlife, irrigated crops, livestock and dairy products or pose an external radiation hazard.

3 Public Health Protection

The disposal of by-products from sewage treatment plants may constitute a health hazard. The use of digested sewage sludge and/or sewage effluents for agricultural or horticultural purposes should not be done unless these by-products are suitably treated to protect the public health.

II METHODS

Some of the most effective methods employed in maintaining water quality and protecting the public health is to provide frequent plant inspections, require monthly operational reports, and conduct plant sampling surveys.

A Plant Inspections

Sewage treatment plant inspections are generally performed on an impromptu basis. It has been found that planned inspections often result in superficial activity to produce a satisfactory appearance for the inspection. The use of inspection forms has been found to be beneficial since these may serve as a guide to the engineer conducting the inspection. A copy of the completed inspection form should be given to the owner of the plant so that he may be aware of any plant deficiencies that require correction.

B Monthly Operational Reports

Monthly operational reports are required to show the effectiveness of the treatment plant at all times. In some states, report forms are provided for the various types of sewage treatment facilities. These fall into the following general categories:

Primary or general purpose

Extended aeration plants

Secondary plants

Stabilization ponds or oxidation lagoons

In order to determine the effectiveness of the sewage treatment plant, the following data are required:

1 The quantity of flow (million gallons per day) handled at the plant each day.

2 The pH of the raw sewage, the plant effluent and the digester supernatant (where possible) each day.

3 The settleable solids content of the raw sewage and the plant effluent at least twice a week which shall not be on the same or consecutive days.

4 BOD's if possible or relative stability tests at least once a week.

5 Sludge pumped to digester daily.

6 Chlorination residual at least once a day.

7 Pounds of chlorine used per day.

8 The man hours spent in plant operation and maintenance each day. Time spent in maintenance of pump stations should also be included.

9 Remarks or comments concerning plant operation as they occur.

10 Materials and costs data for each month as indicated.

C Plant Sampling Surveys

Plant sampling surveys are conducted periodically to determine the efficiency of the various treatment processes and to calculate the waste discharge loadings. In general, the technique is to composite samples of the influent and effluent over as long a period as possible, preferably 24 hours. The samples thus collected are refrigerated and returned to the state laboratory for analyses.

III RESULTS

A As a result of plant inspections and sampling surveys, the efficiency of the treatment plant is often improved. Since every plant has been designed to treat a specified amount of waste, the theoretical efficiency of each unit can be compared with the actual efficiency and suggestions made for improving over-all plant performance.

B The maintenance of water quality standards in the receiving stream is of major concern. The sewage treatment plant surveillance programs have proven their usefulness in helping to maintain these water quality standards.

ACKNOWLEDGMENT

Certain portions of this outline contains training material from prior outlines by Edgar R. Lynd, Supervisor, Municipal Waste Treatment Program, State Sanitary Authority, Portland, Oregon.

This outline was prepared by Lyman J. Nielson, Sanitary Engineer, FWQA Training Activities, PNWL, Corvallis, Oregon.

THE DEVELOPMENT AND SURVEILLANCE OF WATER QUALITY STANDARDS FOR DOWNSTREAM WATER USES

I DEVELOPMENT OF WATER QUALITY STANDARDS

A Water Pollution Control Act (1965 revision)

B Guidelines for Establishing Water Quality Standards

C National Technical Advisory Committee

D Pacific Northwest Pollution Control Council

E Relationship of Water Uses, Water Quality Requirements, and Water Quality Standards

F Limiting Water Quality Parameters

- 1 Public water supply
- 2 Industrial water supply
- 3 Agricultural uses
- 4 Fish, aquatic life, and wildlife
- 5 Recreation and aesthetics

G Status of Water Quality Standards in the Northwest

II SURVEILLANCE FOR WATER QUALITY STANDARDS

A Schedule of Municipal and Industrial Water Treatment Requirements

B FWPCA Surveillance Network

C State Water Pollution Agency Monitoring

D Other Agency Monitoring

E Data Handling, Storage, and Retrieval

III MANAGEMENT OF WATER QUALITY

A Flow Regulation

B Seasonal Waste Loadings

C Seasonal Water Uses

D Interagency Management

This outline was prepared by James L. Agee, Director, Northwest Region, FWQA Portland, Oregon.

SAMPLING AND CONTROL TESTS FOR SEWAGE TREATMENT PLANTS

I SAMPLING OF SEWAGE

A The value of any testing result depends on the integrity of the sample. The object of sampling is to collect a portion of sewage small enough to be conveniently handled in the laboratory and still representative of the sewage to be examined.

B Certain general principles should be followed when sampling, although conditions vary in different plants and the sampling procedure must be adapted to each plant.

1 The sample should be taken where the sewage is well mixed.

2 Large particles should be excluded.

3 No deposits, growths or floating material that have accumulated at the sampling point should be included.

4 Samples should be examined as soon as possible. If held for more than one hour, they should be cooled by icing.

5 The collection of samples should be made as easy as possible to encourage regularity of sampling.

C Two types of samples may be collected, depending on the time available, the tests to be made, and the object of the tests.

1 Catch or grab samples consist of a portion of sewage taken at one time. Grab samples are not representative of the average sewage since they reflect only the condition at the instant of sampling.

2 Integrated or composite samples consist of portions of sewage taken at regular time intervals, the volume of each portion being proportional to the sewage flow at the time it is collected. This type of sample eliminates the effects of intermittent changes in strength and flow.

II CONTROL TESTS

A Dissolved Oxygen

1 Dissolved oxygen analyses are necessary to indicate the levels of oxygen present in the treatment system in order to prevent overloading conditions. Tests on final effluents and receiving waters provide a quick monitor of the treatment.

2 Samples must be taken with care in order to prevent introduction of atmospheric oxygen.

3 The Winkler method is the standard chemical procedure for the measurement of dissolved oxygen.

4 A variety of dissolved oxygen probes which provide an instrumental read-out are now available for testing purposes.

B pH or Hydrogen Ion Concentration

1 Criteria such as pH indicate environmental acceptability and significant changes in operational conditions.

2 pH tests should be performed regularly on grab samples.

3 A comparator employing standard colored glass discs and pH indicator solutions may be used.

4 More precise pH determinations are made by the use of an electrometric pH meter.

C Solids

1 Solids separation and disposal is generally the dominant process in treatment plant operation. Determination of solids on composited samples provides the most adequate monitoring of this material.

2 Total solids are determined by evaporation in a tared container.

3 Settleable solids may be determined from the volume or weight of solids collected from a known sample volume after a specified interval.

4 Suspended solids usually are obtained by the weight of residue collected by membrane, paper or gooch crucible filtration.

5 The relative fractional loss on ignition determines the volatile matter present

in solids samples. The volatile fraction tends to decrease in amount and availability during treatment.

D Chlorine Residual

1 Chlorination provides the proper disinfection to reduce the bacterial population to a safe level.

2 Grab samples are used and must be taken at a point where the chlorine is well mixed with the sewage.

3 If possible, the sample should be taken at a point where the chlorine has been in contact with the sewage for fifteen minutes.

4 Usually a comparator employing standard color discs and orthotolidine is used for the chlorine residual test.

E Determination of Coliform Group Bacteria

1 Testing for the presence of intestinal bacteria in the plant effluent provides a monitor for bacterial removal and disinfection.

2 Catch samples are used for bacteriological tests. Since the coliform test is ordinarily applied to samples of chlorinated sewage, sample bottles must contain sodium thiosulfate to destroy residual chlorine at time of sampling.

3 Samples should be examined as soon as possible after collection.

4 The standard lactose broth fermentation test to determine most probable number is generally used.

5 The membrane filter method provides direct enumeration of coliforms and quicker results are possible using this technique.

Note: Standard procedures and equipment for performing the above tests are available in Standard Methods for the Examination of Water and Wastewater, Twelfth Edition, published by APHA, AWWA and the Water Pollution Control Federation.

This outline was prepared by Donald S. May, Microbiologist, Pacific Northwest Water Laboratory, Corvallis, Oregon.

SECTION VI

APPENDIX

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GLOSSARY - WASTEWATER TREATMENT TECHNOLOGY

This is a selected list containing the key ideas of terms likely to be encountered in treatment technology.

ABSORPTION - The taking up of one substance into the body of another.

ACRE FOOT - A volume term referring to that amount of liquid 1 acre in area and a depth of 1 foot. 43,560 cu. ft.

ACID - Most commonly refers to a large class of chemicals having a sour taste in water, ability to dissolve certain metals, bases or alkalies to form salts and to turn certain acid-base indicators to their acid form. Characterized by the hydrated H^+ ion.

ACTIVATED SLUDGE - A process used for purification and stabilization of wastewaters by mixing of the solids concentrate from previous contact with raw or settled wastewaters under turbulent oxygenating conditions for sufficient time to permit transfer of nutrients to the solids phase, partial biodegradation and clarification of the water before discharge.

ADSORPTION - The taking up of one substance upon the surface of or interface zone of another substance.

ADVANCED WASTE TREATMENT - Renovation of used water by biological, chemical or physical methods that are applied to upgrade water quality for specific reuse requirements. May include more efficient cleanup of a general nature or the removal of components that are inefficiently removed by conventional treatment processes.

AERATION - The operation of adding oxygen to, removing volatile constituents from, or mixing a liquid by intimate contact with air.

AERATION PERIOD - A theoretical time usually expressed in hours equal to the volume of the tank divided by the volumetric rate of flow.

AEROBIC - A condition characterized by an excess of dissolved oxygen in the aquatic environment.

For more scientific definitions or unlisted terms, consult the list of references at the end of the glossary.

AEROBIC BACTERIA - Organisms that require dissolved oxygen in the aquatic environment to enable them to metabolize or to grow.

AGGLOMERATION - An action by which small particles gather into larger particles that are more readily separated from the liquid by sedimentation or other means. May be the result of biological, chemical or physical factors.

AIR LIFT - A pump consisting of a vertical pipe immersed in a liquid into which air is mixed to reduce specific gravity of the air-liquid mixture. The net effect is to raise the liquid level in the discharge pipe.

ALGAE - Primitive plants, one or many celled, usually aquatic and capable of growth on mineral materials via energy from the sun and the green coloring material, chlorophyll. Generally considered as the primary source of food for all other organisms.

ALKALINITY - A term used to represent the sum of the effects opposite in reaction to acids in water. Usually due to carbonates, bicarbonates and hydroxides; also including borates, silicates and phosphates.

AMPEROMETRIC CHLORINE RESIDUAL - A means of determining residual available chlorine with phenyl arsene oxide (PAO) titration using current response as an indicator of equivalence. For wastewater, the PAO preferably is used in excess with iodine backtitration.

ANAEROBIC - A condition in which dissolved oxygen is not detectable in the aquatic environment. Commonly characterized by the formation of reduced sulfur compounds from the use of bound oxygen from sulfates as an hydrogen acceptor.

ANAEROBIC BACTERIA - Organisms that can metabolize and grow in the absence of dissolved oxygen. Their oxygen supply is obtained from the bound oxygen such as in sulfates, carbonates, or other oxygen-containing compounds.

ANION - A negatively charged ion in water solution. May be a single element or a combination of elements, such as the Cl^- ion in a water solution of NaCl (common table salt) or $SO_4^{=}$ ion in a sulfuric acid solution.

ASSESSMENT - A legal financial obligation of the property owner in an irrigation, water, drainage or sanitary district, created for the purpose of financing the construction and operation of facilities required to protect and enhance public benefit within the district.

ATTACHED GROWTH - Plant or animal growth that tends to seek a solid surface for a point of attachment from which to grow, in contrast with free-swimming or suspended organisms.

ATOM - An extremely small unit or particle of an element consisting of a positively charged nucleus and one or more negatively charged electrons. Atoms of different elements are different in mass and the number of electrons. Electrons may be located in the nucleus or externally. The external electrons determine chemical combining power.

ATOMIC WEIGHT - A relative mass of an atom of an element compared to carbon-12. May be expressed in grams (g), pounds or other consistent weight units when used for process control.

AVAILABLE RESIDUAL CHLORINE - Generally refers to that part of the chlorine that will react with ortho tolidine or amperometric tests and exhibits significant germicidal activity.

AWWA (AMERICAN WATER WORKS ASSOCIATION) - An organization composed of individuals engaged in research, design, operation and control in the advancement of knowledge related to potable water supply

BACTERIA - Primitive organisms having some of the features of plants and animals. Generally included among the fungi. Usually do not contain chlorophyll, hence commonly require preformed organic nutrients among their foods. May exist as single cells, groups, filaments, or colonies.

BACTERIACIDE - Any component that will kill or destroy bacteria.

BACTERIOSTATIC - A condition during which the normal metabolic functions of bacteria are arrested until favorable conditions are restored.

BACTERIOLOGY - See Microbiology.

BAFFLE - A deflector or check such as a vane, guide boards, plates, grids, grating, or similar devices used to control the flow distribution or velocity of liquid in a channel or basin.

BAR RACKS (SCREENS) - A coarse screen usually consisting of bars spaced with 1 to 5 inch openings to trap roots, branches, rocks, rags, and other large materials that may be encountered in the flow of a channel or conduit.

BASE - A foundation, plate, natural or engineered support upon which a structure, channel, machine, or other device is mounted.

Chemical: A base includes a large variety of chemicals opposite in reaction to acids (alkali).

BED LOAD - Generally refers to the oxygen demand requirements of benthic deposits, sludge, muck, attached growths, moving materials, living or dead that are exerted upon waters as a result of bottom or boundary dynamics.

BENTHIC DEPOSIT (BENTHOS) - Refers to the accumulated deposition of cell mass living or dead that collects at the bottom of a stream impoundment where velocity or catchment permits.

BIO-CHEMICAL - Resulting from the combined activities of biological and chemical transformations. Usually measured in terms of the ensuing chemical changes.

BIODEGRADATION - The stabilization of wastewater contaminants by biological conversion of pollutants into separatable materials at a higher oxidation state.

BIO FILTER - See Trickling Filter.

BIOLOGICAL PROCESSES - Activities of living organisms to sustain life, growth, and reproduction. Commonly the processes by which organisms degrade complex organic material into simpler substances at a higher oxidation state to obtain energy for life processes and growth of new cell mass.

BIOLOGY - The science and study of living organisms, characteristics and behavior.

BOD - Biological or biochemical oxygen demand. A test for estimation of wastewater polluting effects in terms of the oxygen requirements for biochemical stabilization under specified conditions and time.

BRIDGING - A condition in which particulates or solids concentrates that would normally seek the lowest level of a restricted channel or basin, tend to hang up on sidewalls. The bridged material commonly may settle again with vibration, agitation, a change in flow direction, or increased flow velocity.

BTU (BRITISH THERMAL UNIT) - That amount of heat that will raise the temperature of one pound of water one degree Fahrenheit.

BUFFER ACTION - An action exhibited by certain chemicals that limits the change in pH upon addition of acid or alkaline materials to the system. In surface water, the primary buffer action is related to carbon dioxide, bicarbonate and carbonate equilibria.

BULKING - A condition, usually related to activated sludge processing, in which the sludge solids separation from the liquid is inhibited. Rapid growth, filamentous organisms, and certain other factors that are but vaguely understood, tend to produce a low density thin sludge that settles very slowly and has limited compactability.

BURNER, WASTE GAS - A device for burning the excess gas from sludge digestion.

CALORIE - That amount of heat required to raise one gram of water one degree Centigrade, or Celsius.

CARBOHYDRATES - Naturally occurring compounds consisting of carbon, hydrogen and oxygen, that are considered as energy foods and precursors of proteins and fats in the natural food chain.

CATALYST - A substance that influences the rate of chemical change but either remains unchanged during the reaction or is regenerated thereafter. Generally applies to acceleration of reaction rates.

CATCH BASIN - A chamber, well or other enlargement of a channel, designed to retain grit and detritus below the point of liquid overflow.

CATION - A positively charged ion in water solution. May be a single element or a combination of elements, such as Na^+ in a water solution of NaCl (common table salt).

CENTI - An expression used to indicate 1/100 of a given standard unit centimeter (cm). 1/100 meter.

CENTIGRADE - A temperature measurement scale in which the freezing point of pure water at sea level is designated as 0^oC and the temperature of boiling water is designated as 100^oC. This is more properly termed the Celsius scale.

CENTRIFUGAL PUMP - A pump consisting of a rotating impeller within a casing having an inlet near the center and an outlet or discharge at the tip of the impeller where centrifugal force is greatest.

CENTRIFUGE - A device for separation of solids or liquids of different densities by rotational energy; heavy materials move outward, less dense materials move toward a central take-off port.

CHANNEL - A natural or artificial waterway which continuously or periodically contains flowing water. A connecting link between two bodies of water with a definite bed and sidewalls to confine the flow.

CHANNELING - A condition in which certain portions of the flow within a channel or basin tend to seek a more limited distribution than that resulting from the confining bed or sidewalls, i. e., the flow may channel along the top, bottom or mid channel depth due to density, temperature, or some form of obstruction to uniform cross sectional flow.

CHECK VALVE (FLAP GATE) - A device to control flow in a pipe or channel limiting it to one direction. Commonly a gate hinged at the top that is limited in movement by a seat in a near vertical position so that it can open for flow in one direction but closed by reverse flow.

CHEMISTRY - A science that deals with the composition and characteristics of substances and their behavior, i. e., the transformations that they undergo.

CHLORAMINES - Products of the combination of chlorine and ammonia. Commonly classified as combined available chlorine.

CHLORINE - A greenish yellow gaseous element having strong disinfecting and oxidizing properties in water solution. It is commercially available as compressed gas, liquid, or in combined form as a powder. It is highly toxic and irritating to skin, eyes, and lungs in significant concentrations.

CHLORINATION - The application of chlorine to water or wastewater for the purposes of disinfection, oxidation, odor control, or other effects. Pre-chlorination - before treatment; post-chlorination - after treatment; in-process chlorination - during treatment.

CHLORINATION CHAMBER - A basin or tank where chlorine is applied to the liquid.

CHLORINE TEST - Commonly refers to one of two methods separately listed: see Ortho tolidine test;
see Amperometric test.

CHLORINE DEMAND - The difference between applied chlorine and residual available chlorine in aqueous media under specified conditions and contact time. Chlorine demand varies with dosage, time, temperature, nature and amount of the water impurities.

CHLORO ORGANIC COMPOUNDS - A broad group of compounds containing chlorine, carbon, hydrogen and sometimes other elements. Generally originating from or associated with living or dead organic materials. This group shows a wide range of toxicities but usually have relatively little oxidizing energy compared to chlorine.

CHLOROPHYLL - The green coloring material or pigments in plants that promotes the photosynthetic reactions forming organic materials from inorganic nutrients and light energy within the living cells.

CLARIFIER - A basin or chamber serving as an enlargement of a channel to reduce flow velocity sufficiently to permit separation of settleable or floatable materials from the carrier water (a sedimentation basin).

COAGULANT - A chemical, or chemicals, which when added to water suspensions will cause finely dispersed materials to gather into larger masses of improved filterability, settleability, or drainability.

COAGULATION - The process of modifying chemical, physical, or biological conditions to cause flocculation or agglomeration of particulates.

COD - A test for the estimation of the contamination of a wastewater in terms of oxygen requirements from a strong chemical oxidant under specified conditions, i. e., Dichromate, 50% sulfuric acid and 145°C for 2 hours.

COLIFORM GROUP - A group of bacteria that inhabits the intestinal tract of man, warm-blooded animals, and may be found in plants, soil, air and the aquatic environment. Includes aerobic and facultative gram negative non-spore forming bacilli that ferment lactose with gas formation.

COLLECTION SYSTEM - The sewerage collection system is comprised of the conduits controlled by public agencies to intercept house, commercial or industrial discharges and transport them to a treatment facility or discharge point.

COLLOID, COLLOIDAL STATE - A state of suspension in which the particulate or insoluble material is in a finely divided form that reamins dispersed in the liquid for extended time periods. Usually cloudy or turbid suspensions requiring flocculation before clarification.

COMBINED AVAILABLE CHLORINE - Generally refers to chlorine-ammonia compounds exhibiting a slower reaction with ortho tolidine, determinable with phenyl arsene oxide after addition of potassium iodide under acid conditions and usually requires higher concentration and longer time to kill in comparison with free available chlorine.

COMBINED SEWER - A sewer designed to carry wastewaters and storm waters in the same channel.

COMBINED SEWAGE - Consists of household, commercial or industrial wastes in combination with roof and surface storm drainage.

COMMINUTION -

a) The act of cutting and screening materials contained in wastewaters.

b) To reduce the size of fibrous or amorphous materials.

COMMINUTOR - A device for cutting sewage solids until they pass through an acceptable screen opening to improve pumping and wastewater processing.

COMPOUND -

a) A combination of two or more atoms having definite physical and chemical characteristics and mutually attracted to each other.

b) Atoms in the elemental state are electrically neutral but the number of external electrons may be increased or decreased in response to conditions and nature of the atom. An atom that becomes electrically charged may combine with another atom of opposite charge to form an electrically neutral compound.

CONCENTRATION -

a) The act of increasing the mass per unit volume of one substance with respect to another, such as concentrating the solids in a sludge from 3% to 6%.

b) A means of designating the ratio of one substance with respect to another, such as 15 mg of suspended solids per liter of water.

CONDITIONING - An action of improving possibilities for subsequent processing such as chemical treatment to improve sludge dewatering or filtering.

CONING - A condition in a clarifier sludge hopper where the solids concentrate or sludge is partially withdrawn to form a cone or channel through which clarified liquid is pumped out while most of the solids remain behind around the cone. Infrequent sludge pumping tends to encourage this condition where the sludge tends to solidify and is resistant to fluid flow.

CONTAMINATION - A general term referring to the introduction of materials into water that make the water less desirable for its intended use. Also introduction of undesired substances into air, solutions, or other defined media (chemical or biological).

CRITERION (pl. CRITERIA) - Something which can be measured. Commonly used as a basis for standards.

CROSS CONNECTION - In plumbing, a physical connection between two different water systems, such as between potable and polluted water lines.

CUBIC FOOT PER SECOND (c.f.s.) - A unit of discharge rate such as one cubic foot of gas per second past a given point.

CURVE -

a) A graphic plotted to represent changes in value of one quantity in reference to another.

b) A deviation from a straight line without a sharp break or angularity.

DATA - Records of observations or measurements of facts, occurrences and conditions in written, graphical or tabular form.

DEBRIS -

a) The remains of something broken down or destroyed.

b) An accumulation of fragments of rocks.

DECAY -

a) To undergo decomposition.

b) Implies a slow change from a state of soundness or perfection.

c) To decay.

DEGRADE - To reduce the complexity of a chemical compound.

DEIONIZED WATER - Water that has been treated by ion exchange resins or compounds to remove cations and anions present in the form of dissolved salts.

DENITRIFICATION -

a) The conversion of oxidized nitrogen (nitrate and nitrite-N) to nitrogen gas by contact with septic wastewater solids or other reducing chemicals.

b) A reduction process with respect to oxidized nitrogen.

DETENTION PERIOD - The theoretical time required to displace the entire volume of a tank or basin at a given rate of discharge. Tank volume ÷ rate of discharge.

DETENTION PERIOD, ACTUAL - The actual time required for a given unit of liquid to flow through the tank or process unit. Usually determined by tracer method and depends upon inlet and outlet geometry, temperature, specific gravity, stratification, and other factors.

DETERGENT - Something used for cleaning. Commonly consists of soap or surfactant plus various additives or associated materials.

DETRITUS - The heavier material moved by natural flow, usually along the channel bed. Sand, grit or other coarse material.

DIAPHRAGM PUMP - A pump consisting of a rubber diaphragm (generally) fastened to a cylindrical casing having inlet and outlet valves. When the diaphragm is raised, liquid enters to be forced out the discharge valve on the reverse stroke.

DIFFUSED AERATION - Aeration produced by introducing air through a dispersing mechanism into a liquid. Sufficient air pressure must be applied to overcome hydrostatic head and diffusor or pipe back pressure.

DIFFUSOR - A porous plate, tube, bag, or other device, through which air is forced into a liquid in the form of small bubbles.

DIGESTED SLUDGE - Solids concentrates stabilized under aerobic or anaerobic conditions to preferentially decompose the more unstable fractions and produce a residue of satisfactory disposal characteristics. To reduce the volatile fraction of the sludge.

DILUTION -

a) To make thinner or more liquid.

b) A ratio, volume or weight of a more concentrated sample or effluent flow compared to that into which it is discharged.

DISINFECTION -

a) To make free of infectious organisms.

b) To kill disease organisms.

DISPOSAL -

a) The discarding or throwing away.

b) For wastewaters, this may represent any method of disposing, but usually involves some degree of degradation and discard in a non-pollutional manner.

DISSOLVED -

a) Those materials dispersed in water in ionic, atomic, or molecular form; an homogenous mixture or solution.

b) Generally clear but may be colored.

c) Present in true solution form.

DISSOLVED OXYGEN (D. O.) - Dissolved molecular oxygen usually expressed in mg DO/1 or percent of saturation.

DISTILLED WATER - A purified water resulting from heat vaporization followed later by vapor condensation to separate the water from non-volatile impurities.

DISTRIBUTOR -

a) A device to control flow into some desired direction or place.

b) A device used to spread the flow evenly across a trickling filter surface or other process unit.

DIVERSION CHAMBER - A basin or tank that may be used to divert part of the flow from a channel. May or may not contain treatment capabilities or a means of returning the diverted flow to the treatment plant when a shock load has passed.

DOSING SIPHON - A device to permit intermittent dosing, such as for a trickling filter. Consists of a chamber that will fill gradually to a fixed level before starting a siphon that permits rapid drainage to the filter or other treatment unit.

DRAINAGE TILE (Filter, or bottom tile) - A vitrified tile underdrainage system laid on the bottom to support trickling filter stone, sand, or other filter media, including sludge drying beds. These are specially prepared blocks or half-tiles containing slots for passage of water or air but restricting bed media penetration.

DRYING - The removal of water by natural or engineered means.

DYNAMIC HEAD, TOTAL - The difference in pressure at the elevation of the pump discharge and the elevation at the pump suction flange, plus the velocity head at the discharge minus the velocity head at the suction flange, all corrected to the same units and datum points.

ECOLOGY - The relation of an organism to its environment; i. e., how is an organism affected by his surroundings such as air, water, heat, noise, contamination, etc.

EFFICIENCY - The ratio of materials out of a process to those into that process usually expressed as a percentage.

EFFLUENT - A liquid or product water discharged from a chamber, basin or other treatment operation.

ELEMENT -

a) Elementary substance.

b) A substance or kind of matter in which all atoms are alike in that they will have the same average relative weight and the same number of external electrons.

ELUTRIATION - A washing operation. Sludge elutriation is an action where digested or process sludge is washed with sewage or effluent to remove fine particulates or certain soluble components. The elutriate is recycled to process waters, the elutriated solids are more readily filtered.

ENDOGENOUS METABOLISM - A diminished level of metabolism in which various materials previously stored by the cells are oxidized.

ENTERIC ORGANISMS - Those organisms commonly associated with the intestinal tract.

ENTRAINMENT - A condition or action that will cause an immiscible substance to be mixed with another. Usually the result of turbulence or entrapment; i. e., air bubbles in aqueous media.

ENZYME - A soluble or colloidal organic catalyst produced by a living organism. Usually they are simple or conjugated proteins that catalyze specific reactions.

EQUIVALENT -

a) Equal in force, amount, or value.

b) Chemical: The atomic or molecular weight of one substance that will react with one unit of weight of another substance; i. e., that weight of an alkali necessary to precisely equalize 1 gram atomic wt. of H^+ ion.

EUTROPHIC - Well nourished; rich in dissolved nutrients.

EUTROPHICATION - An action involving the aging of lakes characterized by nutrient enrichment and increasing growth of plant and animal organisms. The net effect is to decrease depth until the lake becomes a bog and eventually dry land. Man-made pollution tends to hasten the process.

FACULTATIVE BACTERIA - Bacteria that can adapt themselves to growth and metabolism under aerobic or anaerobic conditions. Many organisms of interest in wastewater stabilization are among this group.

FAHRENHEIT - A temperature scale in which pure water at sea level has a freezing point at 32° and the boiling point is 212°.

FATS - Naturally occurring compounds functioning as storage products in the living organisms. Consist of carbon, hydrogen and oxygen in the form of fatty acid esters. Generally semi-solid or oily at normal temperatures.

FECAL COLIFORM - A group of organisms belonging to the coliform group and whose presence denotes recent fecal pollution from warm-blooded animals. Standard tests are available to differentiate the fecal coliform group from the other members of the group which have a lesser sanitary significance.

FERMENTATION - A form of respiration by organisms which requires little or no free oxygen, yielding alcohol and carbon dioxide as end products and releasing only part of the food energy available; i.e., the conversion of sugars into alcohol by enzymes from yeasts.

FILTER - A porous media through which a liquid may be passed to effect removal of suspended materials. Filter media may include paper, cloth, sand, prepared membranes, gravel, asbestos fiber, or other granular or fibrous material.

FILTER CLOTH - Fabric, wire or other material stretched over the drum of a vacuum filter and accessories to support the solids during cake formation and discharge the solids when and where desired.

FILTER FLOODING - The filling of a trickling filter with liquid to a level above the media by closing all outlet parts. Generally to control nuisance organisms such as flies.

FILTER FLY - Small black flies commonly found in or near the trickling filter. Commonly the Psychoda group.

FILTER LOADING - The mass (or volume) of applied oxygen demand or solids per unit of filter area or volume. See load ratio.

FILTER MEDIUM - Any material over which water sewage or other liquid is passed for purification purposes by chemical, biological or physical processes.

FILTER PONDING or CLOGGING - The effect of fine particles on sand filters or organic growth on trickling filters that restricts normal passage of liquid through the filter as a result of filling void spaces.

FILTER RESIDUE - That material which is retained on or in a filter.

FILTER UNLOADING - A phenomenon in which normally attached growth or slime on trickling filter media becomes detached and either partially or completely sloughs off.

FILTRATE - That liquid which has passed through a filter.

FILTRATION RATE - A rate of application of water or wastewater to a filter. Commonly expressed in million gallons per acre per day or gallons per square foot per min.

FINAL SETTLER, CLARIFIER - A settling basin or chamber for the mixed liquor following secondary treatment.

FLAME ARRESTOR - A safety device in the handling of flammable gases. Usually consists of an enlargement in a pipe line containing a metallic grid that allows passage of gas but acts as a barrier to the passage of flame.

FLIGHTS - A cross member of a conveyor system used for collection and transport of the collected material; i. e., the boards fastened to a chain loop on either side of a primary clarifier that pushes scum along the surface to a collector trough and sludge along the bottom to the sludge collector.

FLOAT CONTROL - Commonly a device to control a pump or pumps according to the water level in a chamber or well as indicated by the float. Usually operates a relay to control pump power, number, or speed of pumps in operation.

FLOATATION - A process for separation of solids from clarified liquid that causes particulates to be floated to the surface by means of attached air globules.

FLOATING COVER - A gas tight cover with a water seal supported by digester gas pressure and capable of moving upward or downward with liquid and gas content of the digester.

FLOC - Gelatinous or amorphous solids formed by chemical, biological or physical agglomeration of fine materials into larger masses that are more readily separated from the liquid.

FLOCCULATION - The gathering together of fine particulate materials in a suspension to form loosely associated larger masses of solids agglomerates.

FLUME - A long narrow channel for gravity flow of liquid from one point to another.

FLY AWAY BOD - Wastewater stabilization operations such as trickling filters encourage the development of insect larvae that serve as scavengers during their development. If the adult form of the larvae have functionable wings, the equivalent of oxygen demand consumed during development becomes fly-away BOD.

FREE AVAILABLE CHLORINE - Generally includes that chlorine existing in water as the hypochlorous acid. Characterized by rapid color formation with ortho tolidine. Can be titrated in neutral solution with phenyl arsene oxide and produces a rapid organism kill in low concentrations.

FREE BOARD - The vertical distance from the normal water level in a flume, conduit, channel, basin, or other water enclosure, to the top of the confining structure.

FRESH SLUDGE - Recently deposited sludge from sedimentation tanks that has not been conditioned, processed, or progressed materially into the anaerobic action stage.

FUNGI - Simple or complex organisms without chlorophyll. The simpler forms are one-celled; higher forms have branched filaments and complicated life cycles. Examples are molds, yeasts and mushrooms.

FWPCA - Federal Water Pollution Control Administration, U. S. Department of the Interior.

GAS DOME - A chamber usually mounted on top of the digester cover for separation of gas from scum, foam or liquid.

GAS HOLDER - A tank used for storage of gas from sludge digestion units for the purpose of meeting the gas demand for burners, engines, or other use during non-steady production or use periods.

GATE CHAMBER or GATE HOUSE - A chamber installed for housing devices for controlling flow to various parts of a collection, treatment or distribution system, including valves, gates, and automatic or manual controls.

GAUGE -

a) The action of measuring some item such as flow, level, size, rate, etc.

b) A device for gauging.

c) A size designation or indicator for some definite item such as 20-gauge wire, 16-gauge sheet steel.

GERMICIDE - An agent that kills microorganisms.

GRAVITY SYSTEM - A system of open or closed conduits in which the liquid flows by gravity (without pumping).

GRIT - The heavy material in water or sewage such as sand, gravel, cinders, etc.

GRIT CHAMBER - An enlargement of a channel designed to reduce flow velocity adequately to permit differential separation of sand or grit from organic suspended material. Usually approaches a linear flow velocity of 1 to 3 ft/sec.

GRIT COLLECTOR - A device placed in a grit chamber to collect and to convey the more coarse and dense grit particles out of the chamber and permit return of most of the organic or liquid materials.

HARDNESS - Commonly refers to the chemicals interfering with soap action or producing scale in boilers or heating units. Specifically refers to Calcium and Magnesium salts; sometimes including iron, aluminum, and silica.

HEAD LOSS - The difference in pressure between the inlet and outlet pressure of a given process unit arising as a result of flow resistance within the process unit, such as the head loss due to friction of a filter media and filter residue.

HEAT EXCHANGER COILS - A piping layout designed to circulate a liquid media within the contents of the process unit but without mixing with the process media for the purpose of adding or removing heat; i.e., hot liquids may be circulated within a digester to raise digester temperature.

HUMUS - A brown or black complex and variable material resulting from decomposition of plant or animal matter.

HYDROLYSIS - The addition of water to any chemical compound. Commonly involved in splitting complex substances by addition of water to form more simple compounds.

HYDROSTATIC HEAD - The pressure exerted by a given height of liquid above a given datum point. May be listed in feet of head, pounds per square inch, or other criteria.

IMPELLER - A rotating set of vanes to impart motion to a fluid, commonly within a casing where dynamic energy of fluid increases from the center to the tip of the vanes. May be closed or open depending on a tube or paddle configuration.

IMHOFF CONE - A conical glass container commonly one liter capacity, having the upper larger diameter end open and the closed apex downward with graduations to assist estimation of the volume of settleable solids after an arbitrary time interval for settling (usually one hour).

IMHOFF TANK - A deep two-story tank originally patented by Karl Imhoff. The floor of the upper chamber is slotted for transfer of settleable solids from the settling chamber. The lower chamber serves for anaerobic digestion and storage of solids.

INDICATOR - May include the color change of a dye, electronic sensor response, or other means of estimating the equivalence point of a reaction between two different materials.

INFILTRATION -

a) The entrance of ground water into a sewer through breaks, defective joints, or porous walls.

b) The penetration of water through the soil from surface precipitation, stream or impoundment boundaries.

INFLUENT - That material entering a process unit or operation.

INORGANIC - Being composed of material other than plant or animal materials. Forming or belonging to the inanimate world.

INTERCEPTOR - An intercepting sewer designed to carry the dry weather flow from a community to a treatment plant, but not large enough to carry storm water above some preset ratio to dry weather flow. May be used to collect lateral sewer flows.

LAGOON - A natural or artificial basin used for storage and/or stabilization of wastewater or sludge. Sometimes used for indefinite storage for disposal purposes. Commonly the lagoon depth is greater than a wadable depth but not greater than twenty feet.

LATERAL SEWER - A sewer that discharges into a branch or main sewer and has no other tributaries other than individual house connections.

LIQUID SLUDGE - An organic solids concentrate usually formed by deposition from wastewaters. The water content varies with the origin and nature of the sludge usually has enough water to permit pumping but does not contain significant separatable free water.

LOAD - The load to a process is that which is contained in the inflow to that process. It may be expressed as hydraulic, oxygen demand, solids, or other criteria.

LOAD RATIO - An index of loading, including mass input per unit of capacity per unit of time. Mass may be expressed in lbs., BOD, COD, Susp. or volatile solids, capacity in volume, weight of solids or volatile solids in process, and time, usually in days.

LYSIS - To decompose, loosen, or separate into component parts.

MANHOLE - An opening by which access may be achieved for inspection, maintenance, or repair of a sewer, conduit, or other buried structure or appurtenance.

MANOMETER - An instrument for measuring pressure. Usually consists of a U-shaped tube containing a liquid, the surface of which moves proportionally in one open end with changes in pressure exerted upon the other end.

MECHANICAL AERATION - Aeration produced by mechanical energy of the turbine, pump, paddle, or other device that imparts an intimate mixture of liquid and air.

MEMBRANE FILTER - A flat, highly porous flexible plastic disc, commonly about 0.15 mm in thickness and 47-50 mm in diameter. Membrane filters having a pore size of 0.45μ are used in water microbiology to trap organisms, and, by use of standard media and conditions, direct enumeration by colony count of selected organisms.

MENISCUS - The curved upper surface of a liquid in a tube that is concave upward when the containing walls are wetted by the confined liquid, and convex upward when they are not.

MESOPHILLIC - Medium temperature loving. Organisms capable of optimum metabolic activities at temperatures from about 80°-110°F, 26°-42°C.

METER - The length of a reference platinum bar used as a standard unit of measurement of length in the metric system. 1 meter = 39.37 inches.

MICRO - 1/1,000,000 of a unit of measurement, such as microgram, microliter.

MICROBIOLOGY - The science and study of microbiological organisms and their behavior. Commonly related to the study of pathogenic organisms.

MICROORGANISM - Commonly an organism too small to be observed individually by the human eye without optical aid.

MILLI- - An expression used to indicate 1/1000 of a standard unit of weight, length or capacity (metric system).

Milliliter (ml)	1/1000 liter (l)
Milligram (mg)	1/1000 gram (g)
Millimeter (mm)	1/1000 meter (m)

MILLI EQUIVALENT WEIGHT - 1/1000 of the equivalent weight; usually expressed in milligrams (mg).

MG/L - A unit of concentration on a weight/volume basis: Milligrams per liter. Equivalent to ppm when the specific gravity of the liquid is 1.0.

MIXED LIQUOR - A mixture of return sludge and wastewater in the aerator of an activated sludge plant. Also may be used in reference to mixed aerobic or anaerobic digesters.

MIXING ZONE - An area where two or more substances of different characteristics blend to form a uniform mixture; i.e., chlorine application, heated water, or other discharged materials entering a water mass will show significant differences of chlorine residual, temperature or other criteria, depending upon the sampling location throughout the mixing zone and approach uniform results with respect to lateral, longitudinal, and vertical sampling positions when mixing has been completed.

MOISTURE CONTENT - The content of water in some other material. Commonly expressed in percentage of moisture in soil, sludge or screenings.

MOST PROBABLE NUMBER (MPN) - A statistical method of determining microbial populations. A multiple dilution tube technique is utilized with a standard medium and observations are made for specific individual tube effects. Resultant coding is translated by mathematical probability tables into population numbers.

NITRIFICATION - The biochemical conversion of unoxidized nitrogen (ammonia and organic N) to oxidized nitrogen (usually nitrate).

NORMALITY -

a) A means of expressing the concentration of a standard solution in terms of the gram equivalents of reacting substances per liter.

b) Generally expressed as a decimal fraction, such as 0.1 or 0.02 N.

NUTRIENTS -

a) Anything essential to support life.

b) Includes many common elements and combinations of them. The major nutrients include carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus.

c) Nitrogen and phosphorus are of major concern because they tend to recycle and are hard to control.

ODOR CONTROL - In wastewater treatment this generally refers to good housekeeping in the plant and aeration, chlorination or other operations to prevent onset of malodorous septicity in the wastewater flow.

OILS -

a) Liquid fats of animal or vegetable origin.

b) Oily or waxy mineral oils.

ORGANIC - Substances formed as a result of living plant or animal organisms. Generally contain carbon as a major constituent.

ORGANIC CHLORINE - Compounds containing chlorine in combination with carbon, hydrogen and certain other elements.

ORIFICE METER - A device consisting of a flange set in a pipe section containing an opening smaller than the pipe. Pressure readings above and below the orifice may be related to flow.

ORTHO TOLIDINE CHLORINE TEST - The dye, ortho tolidine, under highly acid conditions, produces a yellow color proportional in intensity to the concentration of available residual chlorine and certain other oxidants or interfering materials.

OUTFALL SEWER - The outlet or channel through which sewage effluent is discharged.

OXIDATION - Chemically: The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound.

OXIDATION POND - A shallow basin employed for the stabilization of wastewaters.

OXYGEN AVAILABLE - That part of the oxygen available for aerobic stabilization of organic matter. Includes dissolved oxygen and that available in nitrite or nitrates, peroxides, ozone, and certain other forms of oxygen.

OXYGEN BALANCE - Refers to the dynamic relationship among the available oxygen assets and the oxygen requirements for stabilization of oxygen demanding materials in a treatment plant or receiving water.

OXYGEN DEPLETION - The loss of oxygen from water or sewage due to biological, chemical or physical action.

PARASITE - A living organism deriving its nutrients at the expense of another living organism, giving nothing in return.

PARSHALL FLUME - A device for estimation of the flow in an open conduit. Consists of a constricting section, a throat, and an expanding section. The throat contains a sill over which the liquid passes. The pressure change over the sill can be related to quantity of flow.

PARTICULATE MATERIAL - Refers to detectable solid material dispersed in a gas or liquid. Small sized particulates may produce a smoky or hazy appearance in a gas; milky or turbid appearance in a liquid. Larger particulates are more readily detected and separated by sedimentation or filtration.

PARTICULATES - Pertaining to small suspended solids in a gaseous or liquid media.

PARTS PER MILLION (PPM) - A unit of concentration signifying parts of some substance per million parts of dispersing medium. Equivalent numerically to mg/l only when the specific gravity of the solution is 1.0.

PATHOGENIC ORGANISMS - Bacterial, fungal, viral, or other organisms directly involved with diseases of plants, animals, or man, are included among this group.

PERCENTAGE TREATMENT - The ratio expressed as a percentage of the material removed from process water in terms of the material entering. Sometimes referred to as reduction.

pH - An index of hydrogen ion activity. Defined as the negative logarithm (base 10) of H^+ ion concentration at a given instant. On a scale of 0 to 14 pH 7.0 is neutral, pH less than 7.0 indicates a predominance of H^+ or acid ions; pH greater than 7.0 indicates a predominance of OH^- or alkaline ions.

PNEUMATIC EJECTOR - A device for pumping sludge, sewage, or other liquid by admitting the fluid into a chamber through one check valve and forcing it out of another by air pressure in the chamber above the liquid.

POLLUTION - Anything appearing in water that renders it unacceptable in terms of established water quality standards. Commonly conditions or contaminants that interfere with subsequent beneficial uses of the water.

POND - A basin or catchment used for retention of water for equalization, stabilization, or other purposes. Commonly less than five feet in depth.

PONDING - With reference to trickling filtration, ponding refers to a plugging of the filter media by slimes or solids to restrict downward movement of wastewater sufficiently to cause surface accumulation of liquid either partially or completely.

PRECIPITATE - The formation of solid particles in a solution, or the solids that settle as a result of chemical or physical action that caused solids suspension from solution.

PRESSURE - The total load or force acting upon a surface. In hydraulics, the term commonly means pounds per square inch of surface, or kilograms per square cm above atmospheric pressure on site. (Atmospheric pressure at sea level is about 14.7 pounds per square inch.)

PRIMARY SLUDGE - Sludge obtained from a primary sedimentation tank.

PRIMARY TREATMENT - Commonly the separation of settleable or floatable materials from carrier water. Usually preceded by pretreatment such as coarse screens, grit separation, comminution.

PROCESS - A series of operations or actions that lead to a particular result. A combination of unit operations that may be assembled and used for a given treatment objective.

PROTEINS - Naturally occurring compounds containing carbon, hydrogen, nitrogen. and oxygen, with smaller amounts of sulfur and phosphorus, and trace components essential to the living cells. An essential food associated with meat and eggs.

PROTOZOA - Single cell or multiple cell organisms, such as amoeba, celiates, and flagellates. Commonly aquatic and generally derive most of their nutrition from preformed organic food.

PSYCHROPHILLIC ORGANISMS - Low temperature loving organisms, or having a competitive advantage over other organisms at lower temperatures; i.e., from about 10°C downward to the freezing point.

PUTREFACTION - Biological decomposition of organic matter with the formation of ill-smelling products, such as H_2S, amines, mercaptans. Associated with anaerobic conditions.

QUIESCENT - Characterized by a lack of or negligible movement of the suspending media, such as liquid or gas. Still or absence of turbulence.

RAW WASTEWATER (SEWAGE) - Used wastewater prior to treatment.

RECIPROCATING PUMP - A pump device using a piston within a casing fitted with suction and discharge valves. Movement of the piston in one direction fills the casing, the reverse movement forces liquid into the discharge line. May be vertical or horizontal.

RECIRCULATION - The return of effluent to the influent of a process unit to reduce influent concentration, stabilize the system, maintain hydraulic flow, to reprocess, or for other beneficial reasons.

RECORDER -

a) A device to keep a continuous or intermittent record of some measured item such as flow, velocity, applied power, etc.

b) An individual who tabulates or maintains records of events, actions or measurements.

REDUCTION -

a) To make smaller or to remove from a given amount of material

b) Chemistry: The removal of oxygen, addition of hydrogen, or the addition of electrons to an element or compound.

RELIEF SEWER - A sewer built to carry the flow in excess of the capacity of an existing sewer.

RESIDUAL CHLORINE - See Available Residual Chlorine.

RETURN SLUDGE - Sludge returned from process to the influent flow. Commonly return activated sludge from a secondary clarifier. Also may include sludge from a clarifier after trickling filtration.

ROTARY DISTRIBUTOR - A device usually mounted on a center post with horizontal arms extending to the edge of a circular trickling filter for distribution of flow over the entire bed surface.

SALT - A chemical compound formed as a result of the interaction of an acid and an alkali (base). The commonest salt is sodium chloride formed from hydrochloric acid and sodium hydroxide. This ionizes in water solution to form Na^+ and Cl^-.

SANITARY SEWER - A sewer designed to receive and to convey household, commercial or industrial wastewater mixtures.

SAPROBIC, SAPROPHYTIC - Organisms living upon dead or decaying organic matter. Organisms that utilize nonliving organic matter as a food.

SATURATION - Commonly refers to the maximum amount of any material that can be dissolved in water or other liquid at a given temperature and pressure. For oxygen, this commonly refers to a percentage saturation in terms of the saturation value, such as about 9 mg O_2/l at 20° C.

SCAVENGERS - Organisms that feed habitually upon refuse or carrion. In water pollution, this commonly refers to worms, insect larvae, bloodworms, sow bugs, and crustaceans. Or, more properly, oligochaetes, chironomids and isopods.

SCREEN - A device with openings, generally having a relatively uniform size, that permit liquid to pass but retain larger particles. The screen may consist of bars, coarse to fine wire, rods, gratings, paper, membranes, etc., depending upon particle size to be retained.

SCREENINGS - Material removed by the screens.

SCUM BOARD - A vertical baffle, above and below the liquid surface of a basin or tank, designed to prevent the passage of or to contain floating material within designated limits.

SCUM BREAKER - A device installed in a sludge digestion tank to disperse surface accumulations. Generally accomplished by means of mechanical agitation, gas or liquid recirculation, to promote mixing and destratification.

SCUM COLLECTOR - A mechanical device for skimming and removing scum or floatable material from the surface of a tank.

SECOND FOOT - An abbreviation for cubic foot per second. A rate term.

SECONDARY TREATMENT - Processes used to convert dissolved and colloidal materials in wastewater to a form that may be separated from the water. Commonly consists of biodegradation and conversion to cell mass in a separatable form with partial oxidation, such as in activated sludge, trickling filtration, or oxidation ponds.

SEDIMENTATION - The process of subsidence and deposition of suspended matter from wastewater by gravity. Also called clarification, settling.

SEPTIC SLUDGE - That sludge which has reached a stage of anaerobic putrefaction (sulfate reduction). Includes that from Imhoff, septic, or sludge digestion tanks.

SEPTIC WASTEWATER (SEWAGE) - Wastewater in which available oxygen has been depleted and the reduction of sulfates has begun. A result of anaerobic putrefaction.

SETTLEABLE SOLIDS -

a) Includes materials that will settle by gravity under low flow velocities.

b) Commonly expressed in terms of the volume of solids accumulating in an Imhoff cone after one hour on a volume basis.

SETTLING BASIN - A natural or engineered enlargement of a channel that reduces velocity sufficiently to permit sedimentation of settleable particulates.

SEWAGE - See Wastewater.

SEWAGE GAS, DIGESTER GAS - The gas produced from anaerobic (septic) sewage solids. Generally contains marsh gas (methane) and carbon dioxide with hydrogen sulfide and other components in minor proportions.

SEWER - A pipe or conduit,generally covered,for the purposes of conveying wastewaters from the point of origin to a point of treatment or discharge.

SEWERAGE SYSTEM - A system of sewers and appurtenances for the collection, transportation and pumping of used waters for a given area or basin. Any treatment device or facility and its outfall conduit are a part of the system.

SHORT CIRCUITING - Hydraulic: A condition in which one part or unit of flow into the basin reaches the outlet in much less time than that required for a uniformly mixed flow. Electrical: A situation in which an electric current is out of place in relation to its controlled pathway.

SLIME - SEWAGE SLIMES - Consisting of organisms growing on wastewater nutrients with the formation of mucilaginous covering, streamers or clumps. May consist of bacteria, molds, protozoa or algae.

SLOUGHING - A phenomenon associated with trickling filters and contact aeration units where slimes build up to a varying degree, then slip off into the effluent.

SLUDGE - Accumulated or concentrated solids from sedimentation or clarification of wastewater. Contains varying proportions of solids in wastewater depending upon source, process, and nature.

SLUDGE BANKS - An accumulation of solids including silt, mineral, organic, and cell mass particulate material, that is produced in the aquatic system characterized by low current velocity, Generally refers to gross deposits of appreciable depth.

SLUDGE CAKE - The solids remaining after dewatering sludge by vacuum, filtration, or sludge drying beds. Usually forkable or spadable, with a water content of 30 to 80%. Also may occur on the boundaries of surface water.

SLUDGE COLLECTOR - A mechanical device, including rake, drag, or suction, for collecting settled sludge from the bottom of a clarifier into a sump or other withdrawal system.

SLUDGE DIGESTION - A process by which organic matter in sludge is converted into more stable or separatable form through the action of living organisms. May be the result of aerobic or anaerobic digestion.

SLUDGE DRYING BED - An area used to discharge wet sludge for drainage and drying. Generally prepared of porous bed material surrounded by sidewalls to contain the sludge while the liquid percolates into an underdrain system. May be covered or uncovered.

SLUDGE FILTER - A device to effect partial water removal from wet sludge,usually with the aid of vacuum or pressure of preconditioned sludge.

SLUDGE SYNTHESIS - The net gain in sludge mass in a process over a period of time as a result of simultaneous growth of cell mass and endogenous oxidation within it.

SLUICE GATE - A gate constructed for adjustment to control the flow in a channel by gate position.

SOLUTION -

a) An homogenous mixture, commonly gas, liquid, or solid in a liquid that remains clear indefinitely.

b) Generally an atomic, ionic, or molecular dispersion in a liquid (may be colored).

c) A water solution of dissolved material.

SPECIFIC GRAVITY (Sp. Gr.) -

a) The weight of a material per unit volume in reference to the weight of water at maximum density.

b) Water at 4°C has a weight of 1 g per ml. The weight ratio of any substance divided by the weight of water is the specific gravity.

SQUEEGEE -

a) A device, generally rubber, used for dislodging and removing solids, scum or other materials from a surface.

b) Metal or wood blades to move sludge solids along the bottom of a clarifier.

STABILITY -

a) The ability of any substance to resist putrefaction.

b) Ability of an engineered structure to resist distortion or overturn when loaded.

STABILIZATION -

a) The activity proceeding along the pathway to stability.

b) In organic wastes, generally refers to oxidation via biochemical pathways and conversion to gaseous or insoluble materials relatively inert to further change.

STANDARD - Something set by authority. Having qualities or attributes required by law and defined by minimum or maximum limits of acceptability in terms of established criteria or measurable indices.

STANDARD METHODS - Methods of analysis prescribed by joint action of APHA, ASCE, AWWA, and FWPCA. Methods accepted by authority.

STEP AERATION - A procedure for adding increments of wastewater at various points along the line of flow in an activated sludge aerator.

STERILIZATION - The process of making a medium free of living organisms such as by killing them, filtering through a porous medium fine enough to be a barrier to the passage of organisms, etc.

STORM OVERFLOW - A device such as a weir, dam, or orifice, in a combined sewer that will intercept design flow but permit excess storm flow to discharge directly. The overflow contains a mixed discharge of storm and other sewer components.

STORM SEWER - A sewer which carries storm water from roofs, surface wash and street drainage.

STUCK DIGESTER - Any of a series of events that results in serious malfunction of the digester. Commonly refers to anaerobic digestion where overloading, temperature control, toxicity, or other factors, result in an excessive acid production with serious limitations of gasification, stabilization, and solids concentration.

SUBSTRATE -

a) The base or media in which an organisms lives.

b) The liquid in an activated sludge aeration tank.

SUPERNATANT LIQUOR - The liquid overlying deposited sludge. Commonly that fraction of liquid in an anaerobic digester located over the deposited material and beneath possible surface floating material.

SURFACTANT -

a) A chemical that, when added to water, will greatly reduce the surface tension of the solution.

b) The surface active component in a detergent mixture.

SUSPENDED SOLIDS - The concentration of insoluble materials suspended or dispersed in waste or used water. Generally expressed in mg/liter on a dry weight basis. Usually determined by filtration methods.

SYNERGISM - Refers to the action produced when two or more substances in combination have a greater effect than that produced by the additive effects of each one separately.

TAPERED AERATION - A procedure for adjusting air input along the line of flow of an activated sludge aerator according to need. Usually requires addition of more air per unit of volume at the inlet end of the aerator.

TERTIARY TREATMENT - See Advanced Waste Treatment.

THERMAL POLLUTION - Refers to heated discharges to surface waterways. The largest contributor of heated discharges is associated with power production.

THERMOPHILLIC - High temperature loving organisms. Generally considered to include organisms having a favorable competitive advantage at temperatures above 110°F or 42°C.

THIEF - A term applied to a sampling tube used to remove a core of sample from a bag or bulk material.

TITRATION - The careful addition of a standard solution of known concentration of reacting substance to an equivalence point to estimate the concentration of a desired material in a sample.

TOC - Total Organic Carbon. A test expressing wastewater contaminant concentration in terms of the carbon content.

TOTAL SOLIDS - Refers to the solids contained in dissolved and suspended form in water. Commonly determined on a weight basis by evaporation to dryness.

TRICKLING FILTER - A treatment process employing downward flow of wastewater over the surfaces of a rock or grid system with a large void space for upward movement of air. Slime organisms accumulate to effect biological stabilization.

UNIT OPERATION - A particular kind of a physical change that is repeatedly and frequently encountered as a step in a process such as filtration, aeration, evaporation, mixing, or pumping.

UNITS OF MEASUREMENT -

English - foot, pound, second.
Metric - centimeter, gram, second.
Abbreviations: ft., lb., sec.
cm., g., sec.

USPHS - United States Public Health Service, Department of Health, Education and Welfare.

USPHS DRINKING WATER STANDARDS - A list of standards prescribed for potable water acceptable for use on interstate carriers. Deal with sources, protection, and bacteriological, biological, chemical and physical criteria--some mandatory, some desired. Official for municipal use only upon acceptance by State and local authorities.

VELOCITY (FLOW) - A rate term expressed in terms of linear movement per unit of time. Commonly expressed in ft per sec (English) or cm/sec (Metric).

VENTURI METER - A device for estimating flow of fluid in closed conduits or pipes. Generally based upon constricting and enlarging pipe sections with pressure at the full size and the point of maximum constriction. Differences in pressure can be related to flow.

VIRUS - A term generally used to designate organisms that pass filtration media capable of removing bacteria. Technically described as a collective term covering disease stimuli held by some to be living organisms and by others to be nucleic acids capable of reproduction and growth.

VOLATILE ACIDS - A group of low molecular weight acids such as acetic and propionic, that are distillable from acidified solution.

VOLATILE MATERIAL -

a) Refers to those chemicals having a vapor pressure low enough to evaporate from water readily at normal temperatures.

b) With reference to dry solids, the term includes loss in weight upon ignition at 600°C.

VOLATILE SOLIDS - The quantity of solids in water that represents a loss in weight upon ignition at 600°C.

WASTEWATER - Refers to the used water of a community. Generally contaminated by the waste products from household, commercial or industrial activities. Often contains surface wash, storm water and infiltrations water.

WASTE SLUDGE -

a) Commonly refers to activated sludge produced in excess of that required for return process.

b) Any solids concentrate to be routed for disposal.

WATER QUALITY CRITERIA - Includes selected analytical measurements with limits designated to be acceptable or unacceptable in reference to water quality standards.

WATER QUALITY STANDARDS - Limits set by authority on the basis of water quality criteria required for beneficial uses.

WEIR - A device used for surface overflow from a tank, basin or chamber. Generally designed to smooth out discharge flow to minimize turbulence within the detention basin. May be used to measure discharged flow.

WEIR BOX - An enlargement of the channel upstream of a weir to reduce the velocity and turbulence before reaching the weir.

WELL -

a) An artificial excavation or shaft that collects water from interstices of the soil or rock.

b) Also an engineered structure for the housing of pumps or other equipment below ground level.

WET OXIDATION - Oxidation of substances such as organic contaminants in water media. Includes biological oxidation and physical chemical oxidation, such as that obtained at elevated temperature, pressure,catalyst or other promoters.

WPCF - Water Pollution Control Federation. An organization composed of individuals engaged in the advancement of knowledge in research, design, operation, and control of water pollution in relation to man and his environment.

YIELD -

a) To give up or relinquish.

b) To bear or bring forth as a result of cell division.

c) To produce as a result of investment of energy, materials, or time.

d) The amount or quantity produced per unit of raw material.

YIELD FACTOR - A decimal fraction or percentage of product per unit of input.

ZOOGLOEA - A jelly-like matrix developed by certain microorganisms at some stage in their life cycle. Commonly associated with sludge flocculation in biochemical treatment operations.

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REFERENCES:

1 Any of the standard dictionaries.

2 Glossary, Water and Sewage Control Engineering. APHA, ASCE, AWWA, FSWA. (1969)

3 Glossary, Ohio Operator Training Committee.

4 Jacobs, Morris B., Gerstein, Maurice J., and Walter, William G. Dictionary of Microbiology. D. Van Nostrand, Inc. (1957)

5 Rose, Arthur and Elizabeth. Condensed Chemical Dictionary, 7th Ed., Reinhold Publishing Co. (1961)

6 U. S. Dept. of Interior, Office of Water Resources Research. Water Resources Thesaurus. (Nov. 1966)

7 Geckler, Jack R., Mackenthun, K. M., and Ingram, W. M. Glossary of Commonly Used Biological and Related Terms in Water and Water Control. Env. Health Series, U. S. Dept. HEW (July 1963)

8 Mathews, John E. Glossary of Ecological Terms. Robert S. Kerr Water Research Center, Ada, OK In press.

This outline was prepared by F. J. Ludzack, Chemist, National Training Center, FWQA, SEC, Cincinnati, OH 45226